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ELECTRIC LIGHTING

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MARINE ENGINEERS

OR

HOW TO LIGHT A SHIP BY THE ELECTRIC LIGHT AND HOW TO KEEP THE APPARATUS IN ORDER

WITH 103 ILLUSTRATIONS

BY SYDNEY F. WALKER

M.I.E.E., M.I.M.E., ASSOC. M.I.C.E., M. AMER. I.E.E.

AUTHOR OF "ELECTRICITY IN OUR HOMES AND WORKSHOPS" "HOW TO LIGHT A COLLIERY," ETC.

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PREFACE.

In the accompanying pages, the Author has endeavoured to unite the experience gained during eight years of actual sea-going work, with that acquired in electrical work during the eighteen years that have elapsed since he left the sea; and to present in a simple and concise form all that it is necessary for marine engineers to know of the construction and management of electric light apparatus, to enable them to deal with any difficulties that may arise in connection with the apparatus under their charge.

In the whole of the matter here written, the Author has had forcibly present in his mind those scenes he took part in during the time he was at sea,—the working and straining of every part of a ship in a heavy sea-way, the facility with which sea-water and briny vapour penetrate to every part of a ship, the constant vibration of every part of her when the main engines are at work,—and in the advice he has given, he has had always before him the first requirement of every apparatus for use on board ship, viz. that it must work under all conditions and be easy of repair, rather than present a very high so-called efficiency.

The Author would repeat what he said in the preface to *Electricity in our Homes and Workshops.* This book is in no sense intended to take the place of standard technical works, although it is hoped that many young electrical engineers may find some of its pages useful. It is intended, as far as possible, to lead up to the works of the eminent men who have so ably written upon the higher branches of the subject, and to create that fascinating interest in the science that will not permit of studies being confined to the mere fringe of the subject here dealt with.

In conclusion, the Author has endeavoured to cover the whole ground within the scope of the task he set himself; but he trusts, however, that if there are any points which he has not rendered clear, marine engineers and others interested in the work, will kindly write to him, or to the publishers, when he will endeavour to put the matter right to the best of his ability.

SYDNEY F. WALKER.

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ELECTRIC LIGHTING FOR MARINE ENGINEERS;

OR,

HOW TO LIGHT A SHIP BY ELECTRIC LIGHT AND HOW TO KEEP THE APPARATUS IN ORDER.

CHAPTER I.

GLOSSARY OF TERMS USED IN THE COURSE OF THE BOOK.

What is Electricity?

The author would advise marine engineers not to trouble themselves very much about this, but rather to make themselves masters of all that can be done by the aid of electric currents, and of all that will happen, whether we wish it or no, whenever the conditions present are such that an electric current can pass. So far as we know at present electricity is closely analogous to heat, light, sound, and the other physical forces. As with all these, work must be done upon some body, or by some body, before electricity is generated; and, as with those forces, whenever work is done in the particular manner favourable to the generation of electricity, then we have all the phenomena attendant on its presence.

Properly speaking we do not *generate* electricity, we transform some other physical force, such as heat, into

electricity; and the latter, in expending its energy, becomes retransformed into magnetism, heat, light, sound, or mechanical force, according to the conditions present. It is the province of the electrical engineer to so arrange his apparatus that these transformations occur in the order and in the manner that are necessary for the doing of the particular work he has in hand; and it will be the author's endeavour, in the following pages, to enable marine engineers to do the same with the electric lighting apparatus under their charge. Properly speaking, too, we do not generate electricity, we create an ELECTRO-MOTIVE FORCE—that is to say, the ability to do work electrically, provided the other conditions are favourable.

ELECTRO-MOTIVE FORCE is the term used by electrical engineers to denote that a certain power exists between two points, that can be used to drive an electric current through any conductor that may be connected to them. It is used in precisely the same way that marine and mechanical engineers use the term PRESSURE, when dealing with work done by steam or water. In fact, the term ELECTRICAL PRESSURE is now often used in place of electro-motive force.

Tension, voltage, difference of potential, are also terms that are used to denote the same thing, the latter meaning really difference of electro-motive force, and being a relic of the very early days of electrical science, when the mass of the earth was supposed to be zero of electrical potential, instead of being, as we now know, a conductor subject to the same laws as other conductors. The VOLT is the unit of electro-motive force. Electrical engineers talk of so many volts at the terminals of the dynamo, between the main cables, or between the cable and the

skin of the ship, where the latter is used as a return conductor, just as marine engineers talk of so many pounds pressure in the steam chest, the cylinder, etc.

And, further, the terms are closely analogous, in that voltage and pressure are both lower after work has been done, and by reason of its being done. The pressure at the exhaust port of a steam-engine is considerably less than at the entry port, and the voltage between electric light mains is less after supplying a batch of lamps, or even after the current has passed through a length of cable.

Resistance is the quality possessed in varying degrees by all known substances, in virtue of which electromotive force is necessary. It is somewhat analogous to inertia in mechanics. The resistance of different substances varies very much. The metals offer very little resistance indeed, in proportion to such substances as porcelain, glass, indiarubber, silk, cotton, etc.; and hence it was the custom for a long time, and is even now to a limited extent, to divide substances into two classes — conductors and insulators, the former being supposed to allow of the passage of electric currents through them more or less readily, while the latter did not allow of it at all. There is, however, no such distinction in practical electrical engineering. There are only good and bad conductors. All bodies conduct. Even the so-called insulating coverings of cables, allow of the passage of very weak currents, under the strain of the low voltages generally used on board ship, and, as will be seen later on, this small current in time may lead to the complete destruction of the covering of the cable, just as the continuous action of sea-water upon the shell of the boiler gradually destroys it. And,

further, most of the insulating covering, which stands well, perhaps for many years, with from 50 volts to 100 volts, the pressures used at present in ship lighting, would probably break down in a few minutes under the strain of the high tensions (6000 to 10,000 volts) that are to be used in connection with the large central station at Deptford.

The metals also vary amongst themselves in their CONDUCTING POWER, or SPECIFIC RESISTANCE, as it is termed; that is to say, the resistance offered by a given volume of each substance as compared with the standard. Silver and copper offer least resistance, or are the best conductors, there being very little difference between them. Iron and steel have six to seven times the resistance of copper for the same dimensions. Lead offers twelve times, German silver twelve, carbon 1500 to 40,000, sulphuric acid 100,000, water 1,000,000, dry air an infinite number of times the resistance of copper.

The resistance offered by any body varies also with its dimensions. The longer a wire of a given size is, for instance, the greater force is required to drive a given current through it; and the smaller a wire of a given length is, the greater resistance it offers. Just as a steam or water-pipe offers a resistance to the passage of the steam or water inversely in proportion to its diameter, and directly as its length, so the resistance offered by any body to the passage of electric currents varies directly as its length, and inversely as the area of its cross section.

The unit of resistance is called the OHM, after the celebrated German professor who discovered the very useful law, also called after him, to which electrical

engineers owe so much. It is the resistance of about one mile of No. 4 copper wire, or half a mile of No. 8 copper wire.

It should also be mentioned that the resistance of all bodies varies with their physical condition, and in particular with their temperature. The resistance of all metals, and of most other substances, rises as their temperature rises: the resistance of carbon falls. This fact is of great importance in the matter of incandescent lamps, since the more current there is passing through a lamp the greater the heat, the lower its resistance, and, up to a certain point, the more current it can take with a given EMF.

ELECTRIC CURRENT is the expression used to denote the fact that electricity is passing through any body, or series of bodies, no matter what the conditions may be; and the strength of the current passing between any two points varies directly as the electro-motive force existing between the two points, and inversely as the resistance offered by the body through which the current passes. This is known as OHM'S LAW, and may be stated algebraically thus, $C = \frac{E}{R}$ where C is the current strength, E the electro-motive force, R the resistance.

THE AMPÈRE is the unit of current. One ampère per second passes through a conductor, using the term to cover all known bodies, when one volt is opposed by one ohm, or when any multiple of these figures rules, as say 500 volts and a resistance of 500 ohms.

Ohm's law is of great importance to electrical engineers and those using electric currents, as it enables them to find any of the three quantities—current strength, electro-

motive force (usually written EMF), or resistance, the other two being given; and, in particular, it enables them to calculate the size of wire or cable required to transmit the current for a certain number of lamps over a certain distance, with only a given loss of pressure in the mains. This will be dealt with more fully when the matter of distributing the current is under discussion.

The heating effect and the work done by an electric current are measured, as in other branches of engineering, by the product of the current strength and the EMF under which it flows. Or W, the work done in time, $t = E \times Ct$, where as before $E = EMF$, and C the current strength.

This formula is sometimes written $H = E \times Ct$; where H equals the total heat generated. The generation of heat being, of course, merely one form of work, sometimes the only form done.

It is sometimes expedient to make use of Ohm's law in order to obtain another formula for the work done, in which current and resistance only shall be represented. Thus, since $W = E \times Ct$, and $C = \frac{E}{R} \therefore E = CR \therefore W = C^2Rt$, or the work done or heat generated, is measured by the product of the resistance multiplied by the square of the current strength.

The Watt is the unit of work, and is equal to the product of 1 volt × 1 ampère; and, of course, to the work done when 1 ampère passes through a conductor whose resistance is one ohm.

Seven hundred and forty-six watts equal 1 horse-power, thus connecting the electrical system of units directly with the mechanical. This must not, however, be taken

for the horse-power used in the steam-engine driving the dynamo. Thus, an incandescent lamp of 16 candle-power requires an expenditure of 60 watts to produce the light of 16 candles, or $\frac{2}{25}$ horse-power; but the power required in the engine is never less than $\frac{1}{10}$ horse-power, and more frequently $\frac{1}{9}$ or even $\frac{1}{8}$ horse-power, owing to the various losses or conversions that take place between the cylinder of the steam-engine and the filament of the lamp. This also will be discussed more fully when dealing with the indicated horse-power required for any electric light installation.

There are, of course, a number of other technical terms used by electrical engineers, just as there are numbers of sea terms used by nautical men, but the above are all that need be defined here.

The Electric Circuit.

In order that any electrical action may take place, with apparatus in use for practical electrical engineering, it is necessary that there should be a complete path for the current, from one terminal or one pole, as it is sometimes called, of the generator, through the apparatus the current is required to work—in this case, the electric lamp—back to the opposite pole or terminal of the generator, and through the latter itself to the point from which it started. Any break in this path causes the lamp to go out; and the interposition of a resistance, such as a finer wire than should be fixed, dirt, imperfect contact at any of the points where connection is made between two conductors, will reduce the light given by the lamp, and may even extinguish it, if the

resistance be sufficiently high to reduce the current below a certain strength. Thus with electric lamps, there must be a complete path from one terminal of the dynamo to the lamp, and through the lamp itself back to the opposite terminal of the dynamo. As will be explained also, when describing how to discover causes of failure, the path through the dynamo itself must also be complete; otherwise no light is obtainable. Electricians call this path The Electric Circuit; and it is usual to talk of the circuit being closed when the path is complete, and the circuit being broken, or open, when some break has occurred. A proper understanding of the principles of the electric circuit is of the utmost importance to successful management of any electrical apparatus. Ohm's Law rules the electric circuit. It is Ohm's law which dictates what current shall pass in any circuit, no matter how it may be made up, whether it consist simply of a pair of conductors leading from the dynamo to a lamp, with all connections properly made, or a number of bad connections, dirty contacts, etc. Suppose, for instance, such a case as the following to occur, one that will be dealt with more fully when treating of sources of failure. The insulation of a branch wire leading to a lamp is damaged, sea-water penetrates to the wire, and commences to eat it away. After the chemical action between the copper and the sea-water has gone on for some time, but before it has resulted in the former being parted in two, its sectional area will be considerably reduced, and its resistance, the resistance of that piece of wire, will increase. Still a current will pass, though its strength will be less than before the wire was damaged, and attention may be

called to it by the light of the lamp being slightly dimmed. This will go on while the chemical action goes on, the metallic conductor becoming smaller and smaller, till at last the continuity of the conductor itself is broken, or is only maintained by the finest of points, and still the lamp may be giving light, burning more and more dimly. And it may even go on burning after the wire is actually parted, though with a poor light, the current passing to it by way of the green copper salts which now connect the two ends of the wire together.

MAGNETISM.

Magnetism, as we know, is the property possessed by a certain form of iron ore, the magnetic oxide, as it has been termed, and by bars of steel which have been rubbed with a piece of the ore, or with another piece of steel which has been already magnetised. The properties of the natural magnet are:—

The ability to place itself in the plane of the magnetic meridian, if free to do so, as exhibited in the compass needle. The ability to attract other masses of iron or steel; and the ability to attract or repel certain portions of other natural magnets. The properties of the natural magnet are exhibited at two points, usually at its extremities, or near them, called its poles, and termed, from the fact that they turn to the earth's magnetic north and south, north and south poles. These names should be north-*seeking* and south-*seeking* poles, from the fact that the magnetic pole which turns towards the earth's N. is not itself a north pole; it possesses the properties of a south pole, one of them being an

attraction for a north pole; and the north-seeking pole of the natural magnet turns to the earth's magnetic north pole, because the earth itself possesses all the properties of the natural magnet, its poles being situated at some little distance from the geographical north and south poles.

In the early days of navigation, it was thought that it was the earth's geographical north pole which attracted the end of the compass needle, and probably many shipwrecks resulted from the error.

The attractions and repulsions between the poles of two magnets, such as the earth and a compass needle, may be well studied by placing a fairly powerful

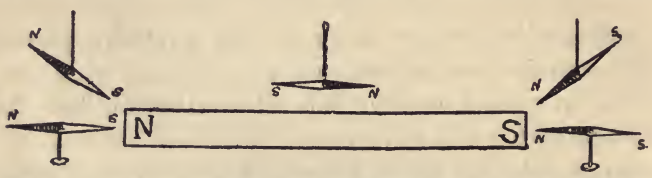


Fig. 1.—Showing the Attractions and Repulsions between the Poles of Steel Magnets.

steel bar magnet in any position, and exploring round it with a small, freely suspended needle magnet. It will be noticed that one end of the needle will be strongly attracted to one end of the bar, when near that end, and the other end of the needle will be as strongly repelled from the same end of the bar. Carrying the needle over the bar, it will be noticed that the attraction between these two gradually ceases, while an attraction is set up between the opposite end of the needle and the opposite end of the bar. It will be noticed also that when over either pole of the bar, that pole of the needle which is attracted to that pole of the bar does

not place itself parallel with the bar, but makes every effort to get into contact with it, placing itself vertical, or at an angle with the vertical, according to its position with reference to the pole which is influencing it; the needle always pointing directly to that pole. And this is exactly what happens with the compass-needle, and the above experiment will explain the troublesome phenomena of "dip."

Fig. 1 shows the above experiment.

Electro-Magnetism.

An electric current is able to imitate all the phenomena of the natural magnet, and to produce very much more powerful effects.

An iron bar, round which a copper wire has been coiled, becomes a magnet as long as a current of electricity is passing in the wire. If free to do so it will place itself in the plane of the earth's magnetic meridian. It will attract other pieces of iron or steel, and its poles will attract or repel the poles of other magnets, or electro-magnets, according to which poles are brought near them.

The electro-magnet may be made of any power, and of any shape that we please; in fact, in modern dynamos, huge masses of iron are formed into the field-magnets as they are termed. The strength of the electro-magnet is measured by what Faraday termed the number of Lines of Force which are passing through it, and this again depends directly upon the magnetic power impressed upon it, and inversely on the magnetic resistance opposed to that power. An explanation of

the process of magnetising an iron bar, or other body, had perhaps better be given here.

The process of magnetising a bar of iron consists, so far as we know, in a twisting of the molecules of the bar in a certain direction, usually so as to place their greatest length parallel with the axis of the bar. But this operation is not confined to the bar which carries the coils of wire in which an electric current is passing. In fact, no iron is necessary for the production of magnetic phenomena. A wire in which a current is passing possesses all these properties, and will impress them on the surrounding space, and it is in virtue of its presence in the neighbourhood of the wire, in the MAGNETIC FIELD created by the electric current passing in the wire, that the iron bar becomes magnetised. The current, in fact, is a magnetising force; and its force is measured by the number of ampères passing, multiplied by the number of turns the wire makes round the bar, or in its neighbourhood, provided they are in the same direction. But the strength of the magnetic field created by the current, or the number of lines of force passing, will depend inversely upon the resistance offered to the magnetising force, which again will depend upon the character and form of the path these lines have to traverse. When, for instance, a straight bar is magnetised, the lines of force pass not only through the bar, but from one end of the bar back through the surrounding space, in curves of increasing radius to the other end. When a bar is bent into the form of a horse-shoe and magnetised, the lines of force pass for the most part directly across the intervening space between the ends, though some pass in larger curves outside. So

that it will be seen that, wherever an electric current is passing, it creates these lines of force in the surround-

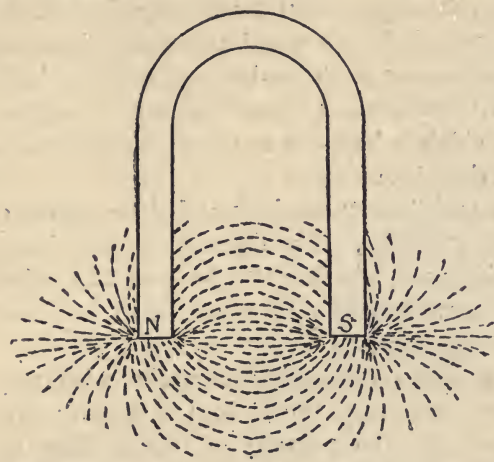


Fig. 2.—Showing the Lines of Force passing between the poles of a Horse-shoe Magnet.

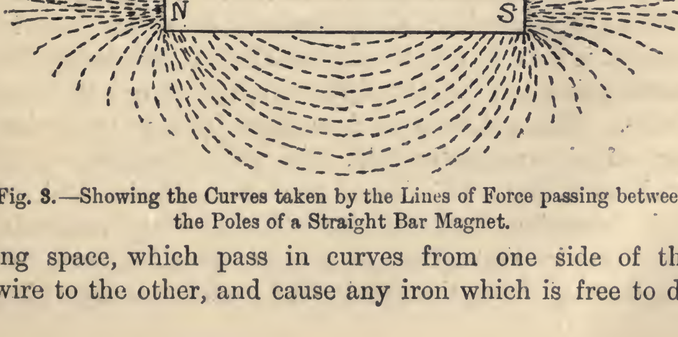


Fig. 3.—Showing the Curves taken by the Lines of Force passing between the Poles of a Straight Bar Magnet.

ing space, which pass in curves from one side of the wire to the other, and cause any iron which is free to do

so, to place itself either in the line of the curve, or as a tangent to it. When the current is carried by a wire which is not coiled upon itself, the lines of force are in circles round the wire, and any small piece of iron or steel brought near such a wire—as, say, an electric light cable—will assume a position which is a tangent to the circle in which it happens to be, whose centre is also the centre of the cable.

Figs. 2 and 3 show specimens of these curves or LINES OF MAGNETIC FORCE. The direction of the lines of force will be the same, whether the body of the magnet is of steel and permanently magnetised, or of iron magnetised by an electric current.

Now, as with an electric current, so with magnetism, substances vary very much in the facility with which they allow of the passage of these lines of force. Iron is the best medium, air probably the worst. Therefore, if the path which any particular set of lines has to traverse is composed largely of iron, and only to a small extent of air or other materials, the lines of force, the magnetic power, will be stronger everywhere, with a given exciting power, than if the path consists largely of air, and only to a small extent of iron. The neighbourhood of a natural or electro-magnet, or of an electric current, is termed the MAGNETIC FIELD; practically the space influenced by the force exerted in or by these bodies. The presence of iron also, in any particular part of the magnetic field, will alter the position of the lines of force, will distort the shape of the field, as it is sometimes termed, by reducing the magnetic resistance in that direction, and so directing some of the lines of force through it that would not otherwise

be found there. Magnetic resistance must not be confounded with electrical resistance, though it follows very much the same laws. It will easily be understood, for instance, that the shorter the path from one magnetic pole to the other, the less resistance is offered to the lines of force or to magnetism. So, also, the larger the sectional area of the body or substance through which magnetism has to pass, the less resistance will be offered. So too, as with electric currents, all bodies conduct the lines of force, no body does so perfectly. But, with magnetism, iron takes the place that metals do with electric currents. Its conducting power for magnetism is far superior to that of any other substance.

The magnetic conductivity of iron also varies with its

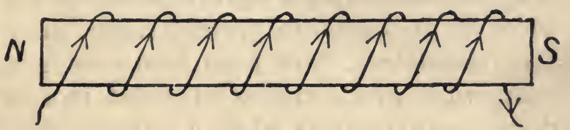


Fig. 4.

quality, just as the electric conductivity of metal does. Cast iron, for instance, offers a very much higher magnetic resistance than wrought iron; and the purer the iron the better the quality, the better it will conduct magnetism. The direction in which a bar of iron is magnetised—that is to say, the position of the end which will turn towards the earth's magnetic north pole—depends upon the direction of the current in the wire, and the direction of coiling.

Fig. 4 shows the direction in which a bar is magnetised, with the current passing as shown.

A rough and ready rule for finding the position of

that pole of the electro-magnet which will turn towards the earth's magnetic N., is the following:—

If you suppose yourself to lie in the path of the current, so that the latter enters at your feet and leaves at your head, the N.-seeking pole will be found on your left hand.

And this is true, whether it be the poles of a magnetised bar you wish to find, or the direction in which a needle magnet, such as a compass needle, will be deflected out of its path by the presence of a wire carrying a current.

INSULATION.

INSULATION is another term which had better be explained before passing on. To insulate means merely to place substances offering a high resistance in the path along which it is sought to prevent either an electric current or magnetic lines of force from passing. Thus the copper wires which are coiled round iron bars to make them electro-magnets when a current passes are wrapped with cotton or silk, so that the current may be caused to traverse the whole length of the wire, instead of passing across from coil to coil. Cables which conduct the electric lighting currents to different parts of the ship are covered with indiarubber, guttapercha, or other compounds. Switches used for controlling the lamps are mounted on hard wood, slate, or porcelain.

So, too, with magnetism. In the dynamo, the horns of the pole pieces are separated either by air or a brass plate. In those dynamos where the poles are downwards, and supported by an iron bed plate, such as the Edison machine, the poles are separated from the bed plate by a sheet of zinc or other metal that offers a

high resistance to magnetism. Insulation, however, in either case, for electric currents or for magnetism, is merely a matter of degree. No matter how great the resistance may be which is offered by the insulating material, some current and some lines of force will pass, in strict conformity with Ohm's law, and that of the magnetic circuit; and all that can be done in the matter is to produce a sufficiently high resistance, so that the leakage current or the leakage magnetism may be inappreciable in proportion to the strength of the working current, or the working magnetic field. The amount of insulation required therefore depends upon the electro-motive force, or the magnetic force present.

For the cables which, lying side by side under the decks, have the full EMF of the service between them. a very much higher insulation is necessary than for the coils of wire on the dynamo, where the EMF present between adjacent coils is very small indeed, as will be seen later on.

Where, too, as in electric light services on shore, very high tensions are used, such as 1000 volts, a very much higher insulation is needed than with the comparatively low voltages in use for ship lighting.

INDUCTION.

The only term remaining to be explained, of those that will be used in this book, is INDUCTION. Induction phenomena are the most puzzling of any, often even to the trained electrical engineer, and always to the man who is just commencing the study of the science.

The processes of induction are very much like those

which go on between the minds of men, leading one man to do what another man orders, but with this difference —there is no free will in the matter. When a magnet orders a current, the latter has to pass, it cannot argue the point. The magnet cannot make a mistake. Induction then is action at a distance. When electric currents flow in wires or cables, as we have seen, their force is not confined to the conductors in which they are passing. They create magnetic fields around the wires. But they do more than this; they create currents in other wires near them, at the moments when they commence and when they cease. As also they cause magnets to move into a certain position with respect to the wire in which a current may be passing; so, too, the motion of a magnet or electro-magnet in the neighbourhood of a wire, or the motion of a wire in the neighbourhood of a magnet, creates or generates a current of electricity in the wire. Strictly speaking, the relative motion of the wire and the magnet creates an EMF in the former, which in turn drives a current through the circuit of which it forms a part, in accordance with Ohm's law, viz., directly as the EMF generated, and inversely as the resistance opposed to it. So that if the moving conductor be a short loop of wire, a comparatively large current will pass through it, even when the EMF generated is small; but if the moving conductor be, say, a straight piece of thin wire, not connected to any other conductor, the current that will pass through it will be practically nil.

Stated shortly, any change in the electrical or magnetic conditions in the neighbourhood of a conductor, whether

produced by the motion of the conductor itself or of another conductor in which a current is passing, by the motion of a magnet or the sudden creation or de-magnetisation of an electro-magnet, even by any change in the strength of the magnetism of a neighbouring electro-magnet or of a current passing in a neighbouring wire, creates electro-motive forces in *all* the conductors present in the vicinity.

There is another form of induction known as electrostatic, where a body with a charge of electricity induces an opposite charge in neighbouring bodies, but the consideration of that hardly comes within the scope of this book.

CHAPTER II.

DYNAMO MACHINES.

The apparatus required for electric lighting on board ship comprises—

1. A dynamo electric machine.
2. An engine to drive it.
3. Cables and wires to connect the dynamo with the
4. Lamps.
5. Switches to control the lamps; brackets, holders, shades, and other fittings to support or protect them.

The Driving Engine.

The author is often asked, by users of electric light both afloat and ashore, "What is the best form of engine for driving a dynamo?" and his reply has always been, "Any well-made engine whose speed accommodates that of the dynamo, that has a good high-speed governor, and that has no very heavy moving parts." A quick-running engine, provided it can be relied upon to keep up to its work under all the conditions of the service it is required for, is well adapted for use on board ship.

During the last ten years, the manufacture of quick-running engines has improved very much. Engineers used to look with doubt at an engine running at 200

revolutions per minute; now it is no uncommon thing to find engines of the ordinary open type, working well, over long periods, at 350 revolutions. So-called high-speed engines, depending on some special arrangement, the author has not much faith in. Their working too often depends on something the engineer in charge may not be conversant with, or upon some special fitting he may not have on board.

The Best Engine for Board Ship Work.

This, in the writer's opinion, is a double cylinder vertical engine, the two cylinders being compounded, and the engines running at anything from 200 revolutions per minute up to 350. Very good results, however, are obtained from a single cylinder engine.

Methods of Driving.

The limited space available, the greater convenience, and the greater compactness have practically settled this question. Nearly every electric lighting plant placed upon ocean-going ships now is furnished with an engine and dynamo on one cast-iron bedplate, the armature of the dynamo being driven directly from the crank shaft of the engine, to which it is coupled.

This arrangement has necessitated the employment of larger dynamos to furnish any given number of lights, than would be necessary if the dynamo were driven by means of belting, etc., though it does not necessitate the armature being of larger diameter.

Other Methods of Driving.

Where there is room, or it is desired to reduce the first cost of the plant, the dynamo may be driven by leather or other belts, by ropes, or by friction.

Of all belts, link leather is the best for driving dynamos; it is so much more flexible, presents no uneven joints, and is so much more readily taken up when required, or spliced when broken.

If a belt is used to drive the dynamo, the pulley of the latter should be provided with a wide flange to prevent the belt coming off. The dynamo should also be mounted on sliding rails, as shown in Fig. 5, which are fitted with adjusting screws, as shown, to enable any slack in the belt to be taken up.

The principal difficulty in driving by means of belts, on board ship, is the short length available for driving, giving the belt a very small grip on the pulley.

This trouble may be overcome by placing a loose pulley near the path of the slack portion of the belt, in such a position that the belt, in passing over the loose pulley, is caused to embrace a larger arc of the circumference of the pulley on the dynamo.

This arrangement, which is shown in Fig. 6, is called a Jockey pulley.

For rope driving, which the author has not seen much used on board ship, but which is used a good deal on shore, both the driving pulleys on the engine and dynamo are grooved, the grooves being of sufficient depth and diameter to receive cotton ropes of a given size.

These ropes are usually from 3″ to 4″ in circumference, and their number depends on the work to be

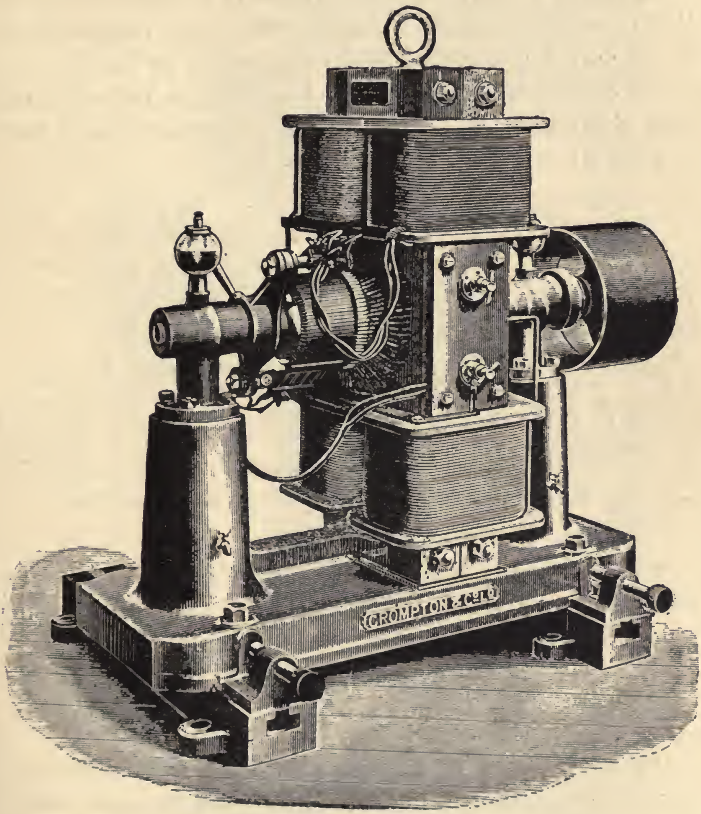


Fig. 5.—Showing Crompton Dynamo, on sliding rails for taking up the slack of the belt.

done, the number of grooves on the two pulleys corresponding of course to the number of ropes required.

It is now usual to have as many separate ropes as there are grooves in the pulleys, each rope being spliced so as to form a complete driving strap by itself. One great objection to this plan, however, is the difficulty that is experienced in getting all the ropes equally taut, so that all may bear the same strain.

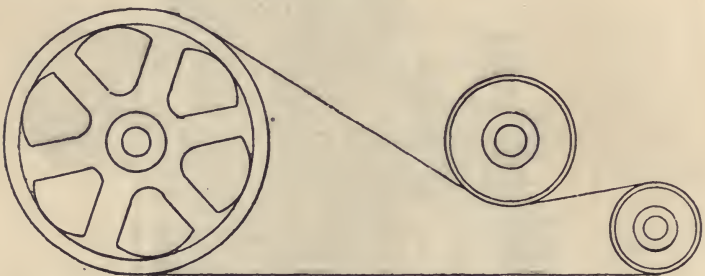


Fig. 6.—Showing arrangement of Jockey Pulley, for driving with a short Belt.

To obviate this, a single rope has been used in a few cases, each end being made fast, and the rope passing round both pulleys as many times as required.

Parson's Steam-Turbine.

As an instance of extremes in high speeds, Parson's steam-turbine, shown in Fig. 7, with its dynamo, which is specially constructed to run at the speed of the turbine, may be mentioned. It runs at from 4000 to 13,000 revolutions per minute, and consists of a series of small turbine or fan wheels, arranged on one shaft; and in some forms of the apparatus, of varying size,

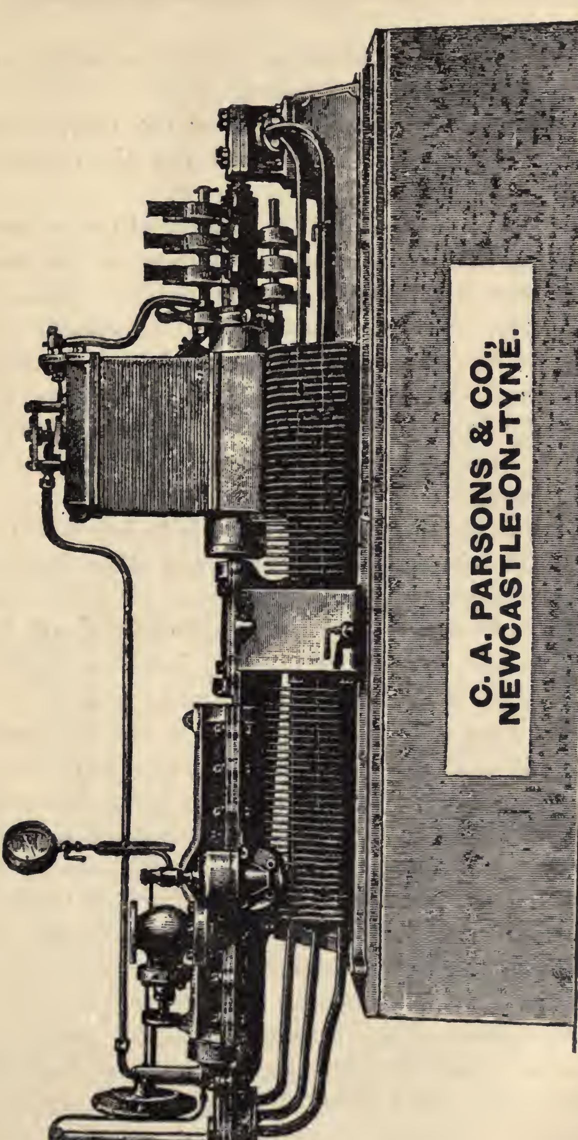


Fig. 7.—Parson's Steam-Turbine, with Dynamo attached.

increasing from the point where the steam enters, so as to act as a compound engine does.

The steam enters at the centre of the length of the turbine and exhausts, either into the air, or into a condenser, at each end.

Fig. 8 shows a section of the interior of the turbine.

It was a complaint in the early days of the steam-turbine, that it consumed a good deal of steam. In recent years, however, considerable improvements have been made, as reports of Professor Ewing of Cambridge and Professor Alexander B. Kennedy of London show. By the addition of a superheater, it is stated that the apparatus becomes more economical than the ordinary cylinder engine.

One point that must be very carefully borne in mind, in using Parson's steam-turbine or any other very high-speed apparatus, is that all parts where electric currents are taken off should be kept scrupulously clean, for a very slight film of dirt, or oil, may introduce sufficient resistance into the circuit to cause serious trouble.

Choose, then, a simple engine and a simple dynamo; such as engineers can master and do any repairs to, short of actual re-making. Do not be led away by so-called high efficiencies, requiring apparently less steam, if the high efficiency is purchased at a sacrifice of either simplicity or strength; 5 per cent. or even 10 per cent. of the horse-power absorbed in the electric light engine of even a very large ship is very small in comparison with the total horse-power used; but it takes a lot of "notions" to produce.

Always have spare working parts for engine and dynamo on board; and let the engineers be thoroughly conversant with the method of changing them.

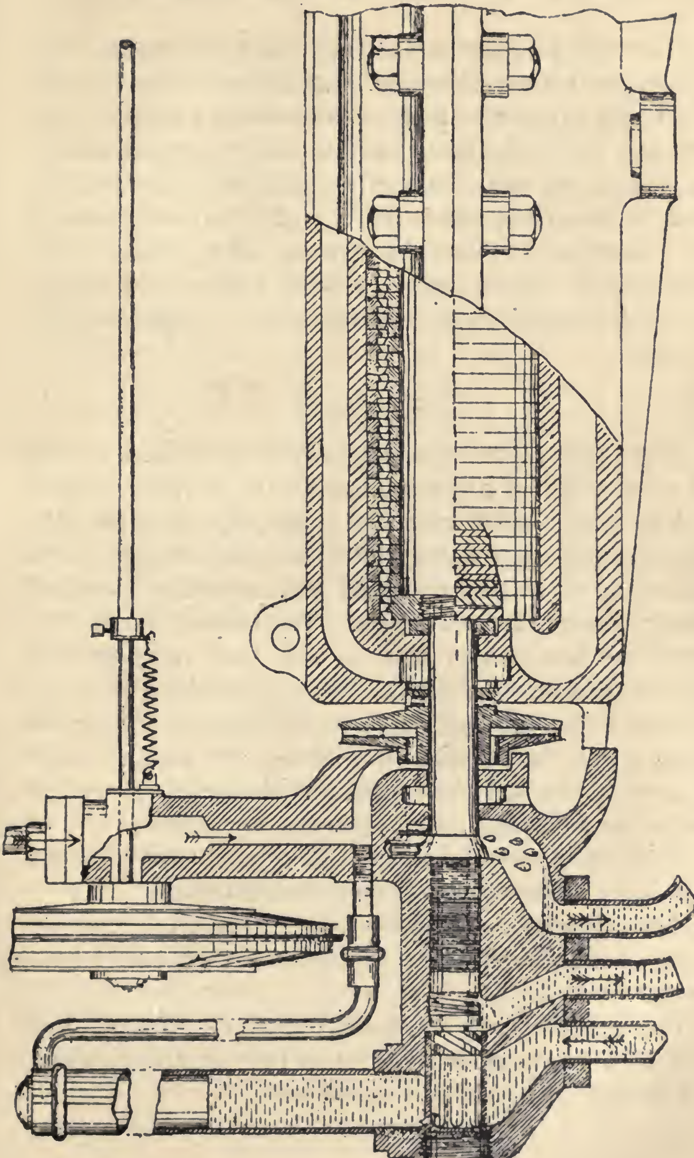


Fig. 8.—Interior of Parson's Steam-Turbine.

Spare parts for the engine need not be detailed. For the dynamo: spare armature complete, with commutator, and, if the voyages be long, even two—or a second commutator; but if the latter be taken the engineer should see one fitted, and thoroughly understand the arrangement of the wires, otherwise he may burn out some of the coils when he starts the dynamo after renewing his commutator. Spare brush holders and a good supply of brushes should also be taken, and a spare set of bearings.

THE DYNAMO.

Before going further it may be well to explain, briefly, the construction of a dynamo machine in its various forms.

A dynamo electric machine is an apparatus for converting mechanical energy into electrical energy in the form of an electric current, and for converting electrical energy into mechanical energy. The latter need not be considered here further than to note that every dynamo which, when driven mechanically, will furnish an electric current, will, when fed with current, give out mechanical power; but that certain differences are usually made in construction between machines designed to act as generators and those designed to act as motors.

In every practical dynamo there are two principal parts—the FIELD-MAGNETS and the ARMATURE.

Both are electro-magnets—that is, bars or other masses of iron, around which coils of insulated copper wire have been wound.

The field-magnets are usually bars or slabs of iron held in a frame which forms the body of the machine, and wrapped with cotton-covered wire.

The armature consists of either a number of iron discs or a coil of iron wire. In either case the iron is held on some convenient form of driving arrangement, such as a spider with a central boss, keyed to a spindle; it is carefully insulated by wrappings of calico or other material, and is then wound, as it is termed, with a series of coils of cotton or silk-covered copper wire.

These coils are connected to each other, just as if the whole of the coils had been one continuous winding, without break, from one length of wire.

The junctions of the coils are connected to separate bars of a cylinder of copper and asbestos or mica, which is also held on the spindle, and revolves with but is insulated from it.

The cylinder of copper and asbestos or mica, is called a commutator, and its office is to arrange the currents that are generated in the coils of the armature all in one direction, with reference to the wires, lamps, etc., outside the machine.

As the armature revolves, currents are generated in all its coils so long as there is a magnetic field provided for it, in the space in which it revolves; or, as electrical engineers express it, so long as there are lines of force passing through the iron core of the armature. The currents which are generated in the copper coils of the armature are in opposite directions in its two halves; and if no arrangement is made for collecting them at the points where the current is reversed they simply neutralise each other, no current being available. In all direct current dynamos, however,—those in which the current furnished is always in one direction,—collectors, known as brushes, are placed at these points, and by

their means the two currents that are being generated in the two halves of the armature find an outlet to the cables, lamps, etc.

The brushes consist either of a number of small copper wires, usually tinned, soldered together at one end, a number of thin copper plates soldered together at one end, or a piece of wire gauze made up into the required form and sewn. In either case they are held in some form of shoe, which is attached to the frame of the machine. The brushes are held against the revolving commutator either by the tension of a spring or by a screw provided for the purpose.

It should perhaps be mentioned that the reason why currents opposite in direction are generated in the opposite halves of the armature is: the coils in the two halves are under the influence of magnetic poles of opposite name; and that in nearly all dynamos, whatever may be their form, the windings of the wires on the field-magnets are always so arranged that pole pieces facing each other are of opposite name. This is important to remember, as not knowing it has sometimes led to a troublesome failure; the dynamo apparently not being able to furnish a current. The pole pieces are the iron extensions forming the space in which the armature revolves.

Alternate Current Dynamos.

In what are known as alternate current dynamos, viz., those in which the current is reversed several times a second, and is delivered to the lamps in that form—the construction, though the same in principle, is somewhat different to that of machines designed for direct currents.

In these dynamos the field-magnets consist usually of a number of short bars of iron, wrapped with cotton-covered copper wire, and held in two frames forming part of the body of the machine. The two frames, with their two rows of short field-magnets, each row arranged in a circle, face each other vertically, leaving a small space between them, in which the armature revolves; the bearings for its spindle being supported by the same two frames which carry the field-magnets. The latter are so arranged that on each frame north and south poles alternate with each other, and in the opposing frames north faces south and south north all the way round. The coils of the armature of the alternator are made flat, and often of copper ribbon, the layers being insulated from each other, the edges of the ribbon facing the field-magnets, and the complete armature usually forming a disc or star. In this form of dynamo, the armature coils, whether of ribbon or wire, form one continuous length, their two ends being connected to two insulated brass collars, carried by the spindle, and known as the commutator, though it is really only a collector. The sectional commutator of the direct current dynamo not only acts as a collector, but it also arranges, commutes, or changes the direction of the currents generated in the coils; that of the alternator merely serves to conveniently pass on the currents to the cables, just as they are generated. In some alternate current dynamos, however, two or three pairs of collars are provided; the armature coils being divided into as many sections as there are pairs of collars. The object of this arrangement is to enable separate circuits to be worked from one machine without special arrangements. Before

the advent of the compound-wound continuous current dynamo this was a decided advantage, as it facilitated distribution, and consequently there were, until lately, several of these machines running in some of those vessels that were the first to be fitted with electric light. It should also perhaps be mentioned that some of the latest types of alternate current dynamos present points of considerable difference from the above description, but these have been designed for use in town lighting.

In order to understand the reason for the use of the alternate current dynamo, it is necessary to go back to the very early days of the electric light. As is well known the arc lamp was the only form of electric light available up to about sixteen years since; and the first arc lamps in really practical use were in lighthouses, that at Dungeness having been at work ever since about the year 1856. Now, as marine engineers know, the lamps used in marine lights have two especial requirements. They must be quite steady, and they must maintain the source of light in the focus of the lens or reflector they are used with. In the arc lamp, as the carbons burn away, the position of the source of light is constantly changing, unless the carbons are moved towards each other as they are burnt away. The continuous current, in passing through the arc, consumes the positive carbon, the one *from* which the current passes, twice as fast as the negative carbon; while the alternate current consumes both carbons about alike, the current, of course passing first from one carbon and then from the other. In addition to this, with the continuous current, the ends of the carbons which form the arc assume different forms as they burn; the positive becoming a sort of blunt point

ending in a little crater, and the negative a cone, with its apex in the arc. The position of the crater and the form of the positive carbon also change very much, so that, as the crater forms a sort of reflector for the arc, it is difficult to maintain the source of light in the focus for long if the continuous current is used. It will easily be understood, therefore, that the problem of constructing a lamp to consume the carbons that shall maintain the arc in one position, is very much easier of solution with the alternating current than with the continuous. Many years after the Dungeness Lights, and some of those on the French coast, were put in, the continuous current dynamo, unless it was constructed with permanent steel magnets, or its magnets were excited by a current of constant strength from another dynamo, was very troublesome indeed, because the exciting power of its field-magnets, and therefore the EMF developed, was constantly changing, and this, of course, would affect both the steadiness of the light and the position of the arc with reference to the focus of its lens, unless the regulating mechanism of the lamp followed every one of these variations, which, of course, it never did. In fact, when, some years after, large electric lights began to be used at dock gates and other places, with series wound continuous current dynamos, those that were successful owed their success to the engine that was used to drive the dynamo. If the engine followed the variations of the arc, running fast when the arc burnt long, that is, the distance between the carbons became long, and going slow when the arc burnt short, as some good-natured engines did, the lamp would burn for hours with only an occasional splutter. Up till very recently there were

some of those old lamps still burning and doing good service.

The first really practical development of electric lighting in later years was at the Paris Exhibition of 1878, when M. Paul Jablockoff exhibited his then celebrated electric candle, with which the Avenue de l'Opera was for some time illuminated, and afterwards our own Thames Embankment.

The Jablockoff electric candle, and all its imitators and would-be supplanters, were worked with alternating currents; and the reason was the same as that given for its use in lighthouse arc lamps, viz. the fact that while it consumed both carbons equally, the continuous current consumed one twice as fast as the other.

The Jablockoff candle consisted of two thin pencils of carbon, held in a framework, and cemented to each other with plaster of Paris, which is a material of very high resistance. A small pellet of carbon connected the two at starting, for the purpose of allowing the current to pass; but as soon as that was burnt, the only path for the current was through the arc, across the plaster of Paris, which was consumed as the carbons burnt down. If one of them had burnt quicker than the other, as it would have done with the continuous current, the lamp must very quickly have gone out, as the carbon ends would have been too far apart for the available EMF to maintain the arc.

This, and the introduction of other lamps at the same time using the alternating current, revived the use of alternate current dynamos just as the introduction of the transformer system has done at the present day. It was even thought, in those days, that continuous current

dynamos were doomed; and the leading French electrical engineer of the day, M. le Comte du Moncel, in reporting on the merits of a then recently-invented dynamo, expressly mentioned, as one of its good points, that it furnished alternating currents.

Later, when the incandescent lamp was invented, it was found that alternate currents could be used with them equally as well as continuous currents; the life of the lamp being, if anything, rather longer when the former were used. And, as in those days, there were no self-regulating dynamos, the ease with which separate circuits could be taken from alternate current armatures, so that the lights turned in or out on one branch did not materially affect the burning of those on the other branches, was a great advantage, and led to the further use of the alternate current. Later on, again, Mr. Ferranti and others were able to generate sufficient current for a very large number of lamps from a comparatively small dynamo.

For all these reasons the alternate current dynamo has had a sort of spasmodic life, now being *the* dynamo *par excellence*, now out of date.

Then, as to the reasons for having so many sets of magnets and so many poles. The reason is, of course, to produce a good many reversals of current in a given time; but the necessity for this is not immediately apparent.

In order to understand it we must dip into another branch of physics, viz. HEAT. It has already been explained that electric currents generate heat when they are opposed, or, as electricians express it, when a resistance is offered to their passage through any body

or bodies. It will readily be understood that time plays an important part in the resultant heating effect. Bodies take a sensible time to become heated to a given temperature, both because heat conduction takes a sensible time, and because a portion of the heat generated or transmitted is transferred to surrounding bodies by radiation and convection. As engineers well know, the temperature which any body assumes in the presence of a source of heat, depends upon the balance which exists between the heat received from the source and the heat given off to surrounding bodies. If more is received than is given off the temperature rises, and *vice versâ*. Further, the time during which a body is exposed to a source of heat naturally has its effect upon the temperature the body assumes; since, if it is receiving more heat per second or per hundredth or thousandth of a second than it is dissipating, the longer the source acts the higher the temperature rises.

Now, an alternating current is to a conductor an intermittent source of heat. Its current commences very weak, gradually increases to a maximum, gradually falls to zero, and then gradually increases again in the opposite direction. It will be evident that if these pulsations are very slow indeed, it will be possible for the conductor to have partially cooled between the times of maximum positive and maximum negative, more particularly if the conductor is so situated that the losses by radiation and convection are large. To obviate this, therefore, the reversals are made of great frequency, many thousands per minute; so that, whether the heat produced be in the arc or incandescent lamp, or for the high temperatures required for welding by electricity,

the conductor never has time to lose the heating effect of one current before it receives another. The reversals, as already explained, are produced by causing the armature to rotate between pairs of electro-magnets whose poles are arranged alternately—first north on one side and south on the other, then south on the side where north was, and north on the other side, and so on; the result of these reversals of the direction of magnetisation of the field being to reverse the direction of the currents generated in the coils of the armature exposed to it.

But there are continuous current dynamos that have more than one pair of electro-magnets, and more than one pair of poles for the armature to rotate between, notably the Victoria,—a design of Mr. Mordey's, modified from the Schückert, the Gülcher, and others.

The reason for these designs are as follows:—In the early days of the Gramme dynamo, the earliest practical machine in the market, it was thought that the wires which passed inside the iron ring, being, of course, continuations of those on the outside, did no useful work, and might even be creating an EMF of their own in opposition to the working EMF of the dynamo. To obviate this Herr Schückert of Nurnberg built a dynamo in which the ring was flattened into the form of a disc, but of larger diameter for a given-sized machine than the Gramme ring it was to improve; and he made his pole pieces into parallel plates, forming a sort of shoe, in which his disc armature revolved. It was subsequently discovered, however, that Herr Schückert had actually created in his improved dynamo the very fault he had suspected in the Gramme, though in another

form. While all the coils of the Gramme ring, no matter what their position, were creating an EMF which added to the total EMF furnished by the armature as a whole; in the Schückert, the coils, during a portion of each revolution, were acting against each other, and it became necessary to reduce the sector of the disc embraced by the polar shoes to very small proportions to avoid this reverse EMF. As the coils outside the pole pieces were doing very little work, a second pair were introduced to partly use up the remainder of the revolution, making four pole dynamos; and in the larger machines three pairs of magnets and six shoes were added, making eight pole dynamos.

The construction of the four and eight pole pole-dynamos necessitates either that there shall be as many pairs of brushes, brush-holders, etc., as there are pole pieces, or the coils which are delivering the same current at the same time must be connected together. Either plan tends to complicate the machine and adds to the cost, especially when it requires repairing; the presence of a number of cross-connecting wires necessitating the greatest care with the connections, and often very highly skilled labour to manipulate.

The next question that arises in connection with the dynamo is, how is the magnetic field, how are the lines of force to be created?

This is done, as already explained, by causing a current of electricity to pass round the coils of copper wire with which the field-magnets are wrapped.

But where is the current to come from? There are two methods of obtaining it.

First, by driving another dynamo and using its current to

excite the field-magnets, as it is termed. This plan *must* be adopted with alternators, as the currents which are so often reversed cannot create a permanent magnetic field of much value. It was also used in the early days of electric lighting, when only arc lights were known, to free the magnetic field from the enormous variations in current strength created by the flickering and occasional extinction of the arc.

The other plan, which is adopted in all dynamos used for ship lighting, except alternators, is to use the current generated by the armature itself, or a portion of it, to excite the field-magnets, and thereby create the magnetic field. But there are three ways of doing this, and the dynamos in which the different methods are used are termed SERIES WOUND, SHUNT WOUND, or COMPOUND SHUNT WOUND. The latter is the one now generally adopted; it is usually known as the COMPOUND DYNAMO.

SERIES WOUND DYNAMO.

In the series wound dynamo the field-magnet coils consist of wire of sufficient thickness to carry the whole current which the armature can furnish with safety, that is, without burning the insulating covering of its coils; and whatever current strength may be required, or may be used, legitimately or otherwise, outside the dynamo, passes round the field-magnets and creates the magnetic field.

This plan, the earliest adopted, presents, as will easily be understood, considerable difficulties in practical work. Should there be, for instance, a break anywhere in the circuit no current can pass, and practically no magnetism is created. In the early days of arc lights, when the carbons of an arc lamp would place themselves just *out*

of contact, this was by no means an infrequent source of trouble, the engine meanwhile doing its level best to knock itself to pieces, its load having disappeared as if by magic. When the incandescent lamp came in, another source of trouble stood revealed, condemning the series wound dynamo.

As will easily be understood, the strength of the magnetic field, the number of lines of force, as electricians mysteriously term it, will depend within certain limits upon the strength of the exciting or magnetising current. So that, using a series wound dynamo, if few lights were on, compared with the possible output of the dynamo, only a small current would pass round the field-magnets, and only a weak magnetic field would be induced, causing the light of the lamps to be low, unless increased speed was given to the dynamo, and *vice versâ.*

Further, if what is technically known as a SHORT CIRCUIT occurred,—that is, if two bare places in the two main leads came into contact, unless the machine was *very* quickly stopped,—a very powerful current would pass through the coils of the armature and field-magnets, generating sufficient heat to burn the insulation and render the machine unfit for work. Hence about this time the shunt wound dynamo came into favour.

THE SHUNT WOUND DYNAMO.

In the shunt wound dynamo a portion of the current generated by the armature is used to excite the field-magnets. On leaving the brushes, the current divides between the cables, lamps, etc., external to the dynamo, and the wire on the field-magnets; the latter being of

much finer wire than on the series wound dynamo, but making a great many more turns, so that the magnetising power is the same. The magnetising power is measured by the product of the magnetising current and the number of turns it makes round the iron.

With the shunt wound dynamo, the EMF at the terminals of the dynamo—that is to say, the number of volts delivered to the cables — varies inversely as the strength of the current that is being used outside. Thus, when the external current is strong, the current passing round the field-magnets is weak, and the EMF the same, and *vice versâ*. The reason that the current round the field-magnets decreases, as the current in the lamps increases, may be given in two ways.

When there are two or more paths for a current, the latter divides itself inversely as the resistance offered by each; or, in other words, directly as the facilities offered, just as if there are two or more pipes to carry off a given quantity of water or steam, the larger pipe will take the most if they are of the same length, and the shorter one, where they are of the same size but different lengths. This explanation, however, is on the supposition that the armature furnishes the same current when many lamps are on as it does when few are on; whereas, up to a certain limit, turning on more lamps on the plan usually adopted on board ship; or, as electricians term it, lowering the external resistance, increases the current furnished by the armature; so that if the cables and lamps take more current in proportion to the field-magnets, as more lamps are turned on, there is more for them to draw from; and it is not clear from this point of view why the field-magnet wires should get

less current when a number of lamps are burning than when only a few are. The actual cause is the working of Ohm's law in the armature. This formula, it will be remembered, may be rendered: electro-motive force = current × resistance; and in this form it enables us to measure the charge upon the initial EMF made by any current passing through any conductor, or, more properly speaking, any resistance.

Thus, supposing the wires on the armature of a dynamo to have a resistance, when running, of ·1 ohm, and the total EMF created by the revolution of the armature at a certain speed, with no current passing in the external circuit, be 50 volts. And let the resistance of the field magnet coils be 50 ohms. When there is no current passing in the outer circuit, the current in the field magnet coils will be all that the armature is called upon to furnish. Roughly, this current will be $C = \frac{50 \text{ volts}}{50 \text{ ohms}}$ = 1 ampère, as the EMF at the brushes, where the two ends of the field-magnet coils are connected, will be very nearly that created by the armature. In fact, it will be 50 volts less the product of the resistance of armature × current passing, or $50 \text{ V} - \cdot 1 \times 1 = 50 - \cdot 1 = 49 \cdot 9$ V.

But when, say, 50 ampères are passing in the outer circuit, these 50 ampères make a charge upon the 50 volts equal to $50 \times \cdot 1 = 5$ V in addition to that made by the field-magnet current. Supposing the total EMF generated by the armature to remain the same, the EMF at the brushes, where the field-magnet coils are connected, will be only 45 V, or thereabouts, and the current passing in the field-magnet coils will now be only $C = \frac{45}{50} = \cdot 9$ ampère, or a reduction of 10 %. And this

reduction of the magnetising current in the field-magnets coils causes a reduction in the total EMF created by the revolution of the armature, and so on, until a balance is reached. As a consequence of the current in the field-magnet coils decreasing as the current in the outer circuit increases, the EMF at the terminals of the dynamo decreases as the number of lamps in use increases, and *vice versâ*, so that the behaviour of the shunt dynamo is exactly the reverse of that of the series dynamo. With the shunt dynamo it is necessary to be careful to lower the speed when many lamps are suddenly turned off, as otherwise the EMF increases so much from the above cause, and also from the engine racing, if not very well governed, that the current passing through the other lamps is also very much increased, and they will be seriously strained; the fact before mentioned, that their resistance lowers as the current passing through them increases, adding to the trouble, as owing to this the strain upon the filament increases at a compound ratio.

On the other hand, it is possible, by constructing the shunt wound dynamo very large in proportion to the work it has to do, to maintain the current in the field magnets, and therefore the EMF at a given speed, practically constant, whether the machine is running an Open Circuit, as it is termed—that is, with no current in the external circuit, or with the full number of lamps for which the dynamo is constructed.

Suppose, for instance, that, instead of the armature resistance in the case quoted above being ·1 ohm, it was ·01, then the charge for 50 ampères, upon the initial EMF of the armature, would be only $\cdot 01 \times 50 = \cdot 5$ V, and the difference between the currents passing in the

field-magnet would be as $\frac{50}{50}$ to 49·5, which would be very trifling, and it will be seen the difference can be made as small as you choose, by lowering the resistance of the armature. In practice, however, it is cheaper to use a compound wound dynamo, as the increased size of the shunt wound dynamo required to effect approximate self-regulation adds greatly to the cost of the installation.

Another point that should be mentioned in connection with the shunt wound dynamo is the, at first sight, curious feature, that when a very large current *ought to pass*, or, as electrical engineers term it, when the dynamo is SHORT CIRCUITED, that is to say, when a conductor of very low resistance joins its terminals, *no current is furnished, as no EMF is* created. As the external resistance decreases, the EMF at the brushes decreases; and though the current in the external circuit increases up to a certain point, after that it also decreases gradually, because the EMF is decreasing faster, owing to the decreased current in the field-magnets, than the outer resistance decreases, and, consequently, both finally come to zero.

Compound Wound Dynamo.

In the compound shunt wound, or compound dynamo, the two methods of winding, series and shunt, are combined. Part of the magnetism of the field-magnets is induced by fine wire coils connected directly to the brushes or terminals of the machine; and the other part of the magnetism is furnished by a few thick wire coils through which the current passes, on its way to the lamps. The result is that the machine is always ready to furnish a current, and if properly constructed, that is

to say, if the proper proportion between the shunt and series coils is observed, the EMF, or tension, at the terminals of the dynamo, is the same if only one lamp is burning, or even if it be furnishing no current outside the field-magnet wires, or running on open circuit, as it is termed, as when the full number of lamps for which it is constructed are burning.

To understand how this perfect regulation is obtained, the action of the two currents may be looked upon as balancing one another. That is to say, as the outside current increases with an increased number of lamps, and the current passing in the shunt coils decreases, so does the current in the series, or MAIN coils, as they are often termed, increase, thereby preserving the magnetism constant or thereabouts.

But this explanation, though passable for a cursory examination of the question, does not give the whole of the facts, and the reader who wishes to be master of his apparatus will do wisely to pursue the subject a little deeper. To understand the whole action then, look upon the compound machine as a shunt wound dynamo, plus the series coils. It was explained above, that the reason why the current in the shunt coils decreases, as the current passing to the lamps outside increases, is because the passage of the current through the copper wire coils of the armature, makes a charge upon the initial EMF created by the revolution of the armature, within the magnetic field provided for it. It must be borne carefully in mind that EMF is what we have to produce, when we wish to do electrical work. Given EMF, applied to any body, and current follows; and the one question to be solved, when we have certain

work to do, is how to provide sufficient EMF to do that work under the conditions. Just as the one question, after all, in steam-engine work of all kinds, is how to provide such a pressure of steam as will do the work under the conditions ruling.

Now, the EMF obtainable from any dynamo depends on three things: The speed at which the armature, or bobbin, as it is often called, revolves; the number of convolutions of wire on the armature; and, the strength of the magnetic field in which the armature revolves, or, as electricians term it, the number of lines of force passing into its iron core.

In any given dynamo the number of convolutions of wire on the armature is, of course, constant; you cannot take your armature out and put a few more coils on when you require more lights. At least, no ready method has been discovered of doing this. Further, with the compound wound dynamo, the speed is also constant. Therefore, if the strength of the magnetic field is to remain constant, while the strength of the current in the inducing shunt coils decreases, the main or series coils must provide as much inducing power, as much magnetism, as many lines of force, as the shunt coils lose.

But the main coils have to do more than that even. As the current for the outer circuit, the cables and the lamps, is taken from the ends of the series coils, the EMF *there* must be constant; and in order that it may be so, the EMF at the brushes and the initial EMF created by the revolving armature must be increased to allow for the charge on them, for the passage of the main current through the series coils, so that the latter must be able to provide not only for the loss in the shunt coils but

also for the addition rendered necessary by its own presence.

In most compound dynamos a portion of this increase is furnished by the shunt coils themselves, owing to the indirect action of the main coils. Where, as is most common, the ends of the shunt coils are connected to the brushes, as the current passing in the main coils increases the strength of the magnetic field in which the armature revolves, the EMF at the brushes increases, thereby increasing the current passing in the shunt coils, and again adding to the strength of the magnetism. This, of course, increases the initial EMF, and so on. So that, in machines constructed on this plan, the EMF at the brushes and the current passing in the shunt coils is higher than would be the case if there were no loss under ordinary conditions as the outer current increases.

In some compound wound dynamos, however, the shunt coils are connected to the terminals of the dynamo, so that the main coils do all the work of furnishing the increased magnetism, both to make up for the loss in the shunt coils and for the charge on the initial EMF arising from their own presence.

It will be seen that the compound wound dynamo must be far and away superior to either series, shunt, or alternating current dynamos, for ship lighting at any rate; since, providing the engine be properly governed, to run at, or nearly at, one speed, lights may be turned in or out at will, without the fear of damaging any part of the apparatus. Further than this, with the compound machine you may have any light of any power at any place, by merely running your cables to it; and you may turn the largest light in or out as you please. Moreover,

when you are not requiring lamps in one place, you can use the power of the machine in another without complication.

It must be remembered, however, that a compound dynamo, constructed to furnish a certain voltage at a certain speed will compound, as it is termed, or will regulate, only at or about that speed. An increase or decrease of speed will upset the balance, though of course it would not be appreciable in the lamps, except to a critical eye, unless the variation in speed was considerable.

To understand this, suppose a compound dynamo constructed to run at 600 revolutions, and to furnish 100 volts at its terminals.

The voltage at the brushes would, of course, be rather more, call it 102 volts. Now, suppose that from any cause the dynamo is made to run at 700 revolutions instead of 600. The voltage would probably be about 115 volts to 120 volts at the terminals, and 118 volts to 123 volts at the brushes. To simplify matters, suppose that there are 115 volt lamps in use in the ship, and she picks up a 100 volt compound dynamo at some port of call, intending to make it answer for the 115 volt lamps by running faster. Now, the shunt coils being very much more powerful than they should have been to fulfil their proper function, the magnetising power of the shunt coils rising with the speed in a compound ratio, there would not be so much for the main coils to make up, when the proper speed for the 115 volt lamps was arrived at. Consequently, when a number of lamps were turned out, the light given by the rest would go down, because the shunt coils would be set

necessarily below their proper current in arranging the speed of the dynamo, to avoid overrunning the lamps. In fact, the conditions would be reversed. Instead of the main coils making up the loss of the shunt, the shunt coil would be set to make up, at full load, what the main coils did not provide. The main coils would do their work anyway, so that the shunt coils could only be allowed to furnish enough magnetism to do the rest; and when the armature was deprived of the magnetism of the main coils, or a portion of it, it would not have the strength it should have had, owing to the shunt being below power, unless the speed was raised.

The reverse, of course, holds good, if a dynamo is run at a lower speed than it is compounded for. Two other points should be mentioned in connection with compound machines.

There will be a limit with every machine, beyond which it cannot be made to compound. It will easily be understood that there is a limit to the strength of magnetism which the iron and other parts of a dynamo will transmit. This limit is well known now by dynamo manufacturers, and they design their machines accordingly. But, supposing the current passing in the outer circuit to be increased beyond the limit at which the increased current in the main and shunt coils induces increased magnetism in the iron core of the armature, then the EMF at the terminals must go down, unless the speed is increased, as the charge for the current passing through the main and armature coils has still to be met.

In such a case, however, the dynamo would probably be overworked.

Another point that should be mentioned is, that it is a very difficult thing indeed to compound machines exactly, and therefore it is wise to have attached to the governor of the engine a regulating apparatus, such as a spring whose tension can be adjusted, or a weight whose position can be moved to allow for a slight variation of speed. Only a slight margin is required, and it is a simple matter, if a voltmeter (an instrument that will be described later on) be placed near the engine, to maintain the light given by the lamps in all parts of the ship quite uniform, no matter how many may be burning.

Perhaps the different methods of winding the field-magnets of continuous current dynamos may be understood better from the diagrams shown in Figs. 9, 11, and 13, and their behaviour from the characteristic curves shown in Figs. 10, 12, and 14.

In Fig. 9 is shown the arrangement of the wires on a series wound dynamo. As will be seen, the whole current, whatever work the machine may be doing, passes round all the coils of the field-magnets.

In Fig. 10 is shown what is termed the characteristic curve of the series wound dynamo. That is to say, the history of its behaviour under varying conditions of the external circuit is shown by the form of the curve.

In the diagram, horizontal distances represent the strength of the current passing through the machine at the time, and vertical distances the electro-motive force corresponding to each current strength.

Thus it will be noticed that the EMF is O when the current is O, and that the former rises very rapidly for a small increase of current up to a certain point, when it remains about stationary, and then slowly bends over.

The explanation of this, which has already been given in another form, is, when no current is passing there is practically no magnetism in the field in which the

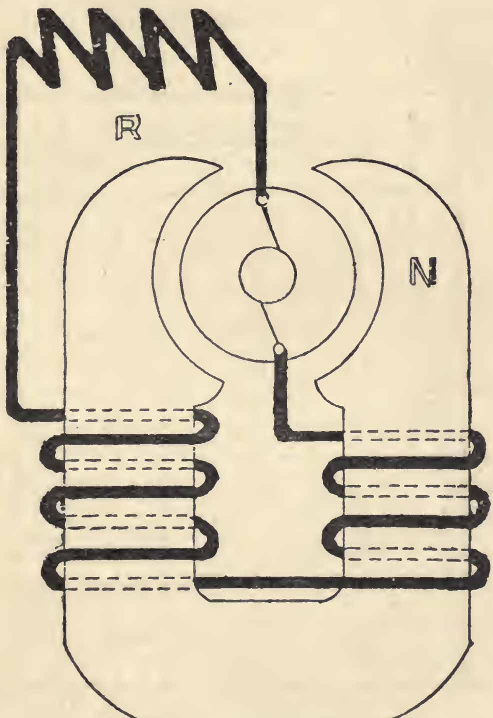


Fig. 9.—Showing, diagrammatically, the winding of Field-Magnets of Series Wound Dynamo.

armature revolves, and, therefore, no EMF is generated. As the current increases the iron becomes more and more magnetised, the EMF rising all the time till a point is reached where the additional charge upon the initial

EMF created by the revolution of the armature is greater that the EMF due to the magnetism produced by the additional current when it begins to fall. The curve is useful in many ways. For instance, it is apparent that the only way in which an increased current can be

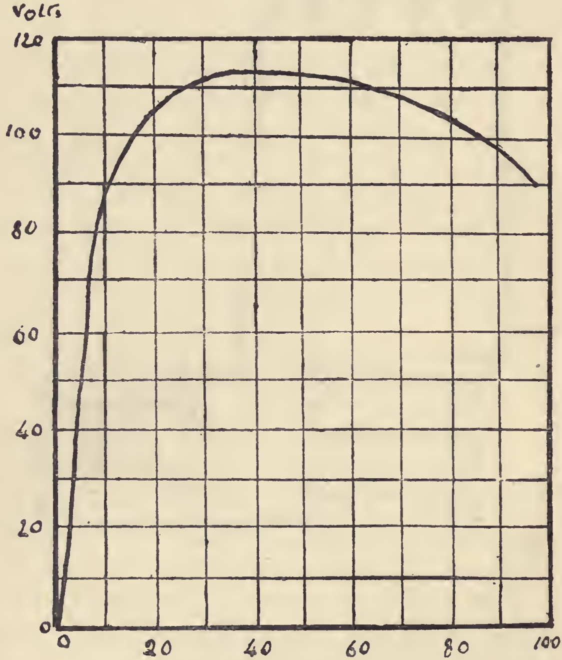


Fig. 10.—Characteristic Curve of Series Wound Dynamo.

made to pass is by a decreased resistance, and, therefore, that a comparatively small decrease in the resistance external to the machine gives rise to a large increase of EMF. Thus, where incandescent lamps are worked from a series wound dynamo, each lamp that is switched

in increases the light given by the others appreciably, without increasing the speed, up to a certain number, while, if many are switched in beyond that number, the light will begin to decrease unless the speed is raised.

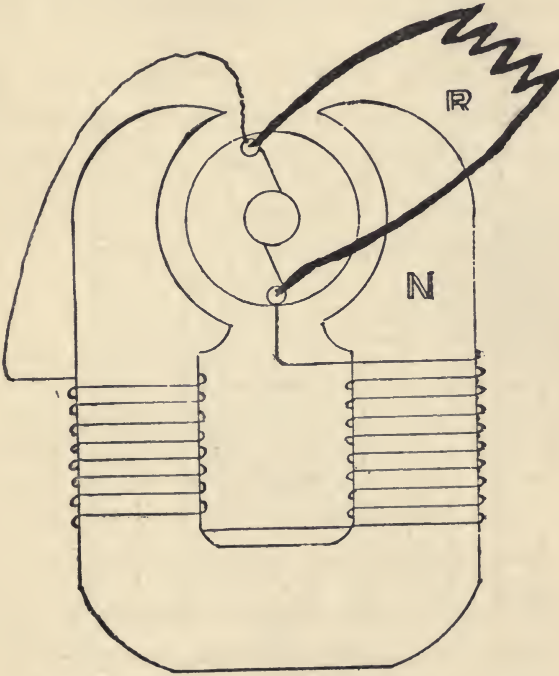


Fig. 11.—Showing, diagrammatically, the winding of Field-Magnets of Shunt Wound Dynamo.

It is understood, of course, that the speed is maintained constant for the curves shown.

Another use of this curve is to show at what point comparatively large increases of current produce but

small increase of EMF, which is of service in many cases.

As an instance of the use of the characteristic curve of the series dynamo, it may be mentioned that series wound machines, which are intended to furnish a number of arc lamps in series, are so constructed that the average

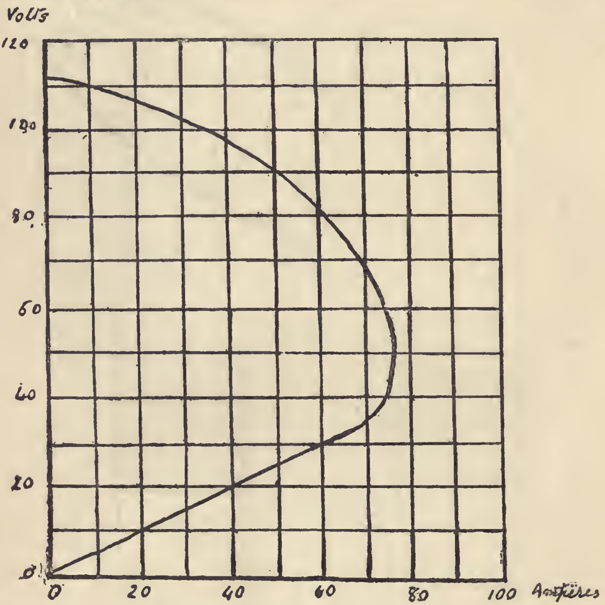


Fig. 12.—Characteristic Curve of Shunt Wound Dynamo

current at which the lamps burn is the medium current of the flat portion of the curve, so that should there be an increase or decrease of current strength, owing to the variations in the lengths of the arcs, the distance between the carbon points, it shall not appreciably affect the EMF at the terminals of the dynamo. In fact, the dis-

covery that there was such a flat in the curve of some series dynamos was largely instrumental in securing the ultimate success of the arc lamp. Keeping the EMF fairly constant eliminated one variable, and the one that would have acted in the contrary direction to that which it was wanted to; since increased current due to shortening of the arcs would lead, as already explained, to increased EMF, and thereby to a further increase of current, consuming the carbons far more rapidly than the normal current would, and upsetting the regulation of the lamp by causing pieces of the carbon to break off.

Fig. 11 shows, diagrammatically, the arrangement of the field-magnet wires, and external circuit in the shunt wound dynamo; while Fig. 12 shows its characteristic curve. It will be noticed that in this machine there are two points where the current is O. These are when there is no work on the machine, no current passing in the external circuit, and when the external resistance is infinitely small, or, as it is usually expressed, when the terminals of the dynamo are *short circuited*, say, by a short piece of wire, or by the cables coming into contact not far from the machine. The reason for this latter phenomenon has already been explained, viz., the charge upon the initial EMF created by the armature so reduces the magnetism of the field-magnets, when the external resistance is infinitely low, as to annul it entirely.

This phenomenon is also very puzzling when first encountered, especially where men have been accustomed to working with a series wound dynamo. With the latter, a rough-and-ready test of whether the machine is in working order, is to take a short piece of wire and momentarily connect the two terminals. If all is right

a large flash is the result when the wire is disconnected. With the shunt wound dynamo no such thing takes place, as, of course, where the action of short circuiting tended to

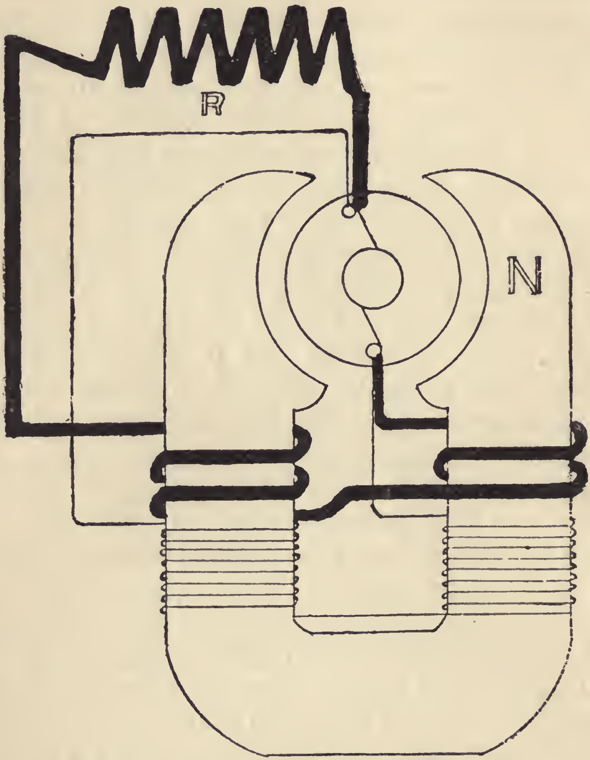


Fig. 13.—Showing winding of Field-Magnets in Compound Shunt Wound Dynamo.

create an EMF in the one case, it destroyed it in the other.

It may be mentioned that the rough-and-ready method of testing referred to should not be used where it can be

avoided, as it strains the dynamo. In the very early days of electric lighting it was excusable, as there were no instruments available; now there are plenty.

It will be noticed that the curve, as shown, bends very gradually as the current increases up to a certain point, and then the current itself decreases even faster than the EMF. This requires some explanation. The only way in which the current taken from the dynamo can be increased is by decreasing the resistance opposed to it, so that the upper portion of the curve represents a decreasing resistance. But it cannot be shown as resistance in the same simple form as current, because, for a portion of the curve, as far as the bend, the figures would go in one direction,—the smaller resistances on the right, while for the remainder of the curve the smaller resistances would be on the left.[1] The meaning of the curve then, is, the EMF at the terminals of a shunt wound dynamo is highest when the external resistance is infinite. It decreases as the external resistance decreases, and at a certain point a further decrease of resistance not only decreases the EMF at the terminals of the dynamo, but also the current passing in the outer circuit, though there is a better path for it. Interpreted into language of every-day life, it stands thus: with a shunt wound dynamo, when only one lamp is burning, the speed of the dynamo being constant, the light given is the brightest that will be obtained at that speed. As lamps are turned on the light given by each lamp becomes less and less, though gradually; but after a certain number are on any addition causes the light

[1] It should be noted that the curves of individual dynamos vary considerably in their form, though they may be of similar winding.

given by all to diminish very rapidly indeed, and by continuing to add lamps the light given by all may be extinguished. A peculiarity of an experiment of this kind would be, that after passing the turn of the curve, the load on the engine would be less and less, though more and more lamps had been added. This is in striking contrast with both the series and compound wound dynamos, where each added lamp adds to the work of the engine.

It should be noted, however, that by modifying the construction of the dynamo, as already explained, the upper portion of the curve can be made as flat as you please. The gradual depression of the curve being due to the charge upon the initial EMF created by the armature, due to the resistance offered by the wires of the armature itself, it is evident that the lower this resistance is made, the smaller this charge will be, and the flatter the upper portion of the curve. Even in this case though, there must be a point at which the curve bends round as shown.

In Fig. 13 is shown the arrangement of the winding of the field-magnets of the compound dynamo. As will be seen, the field is created by the two currents, passing in the two wires, the series and shunt windings.

Fig. 14 shows the characteristic curve of the compound dynamo. The dynamo which compounds perfectly furnishes a horizontal line, up to the point when it is being overloaded. Many compound dynamos, however, also give a slightly lower EMF when few lamps are on.

What is termed a sine curve, shows the behaviour of the alternate current dynamo, during each period, as it is termed.

The vertical distances in the sine curve would represent EMF's, which are only considered, the horizontal line representing zero.

As already explained, in an alternate current dynamo, the current furnished by the armature is reversed many

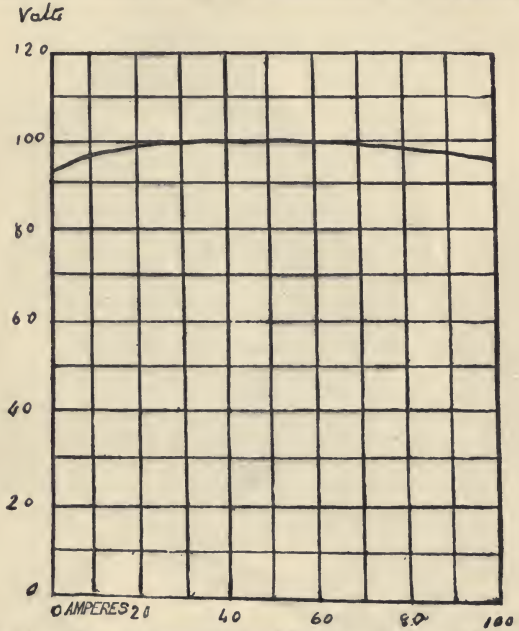


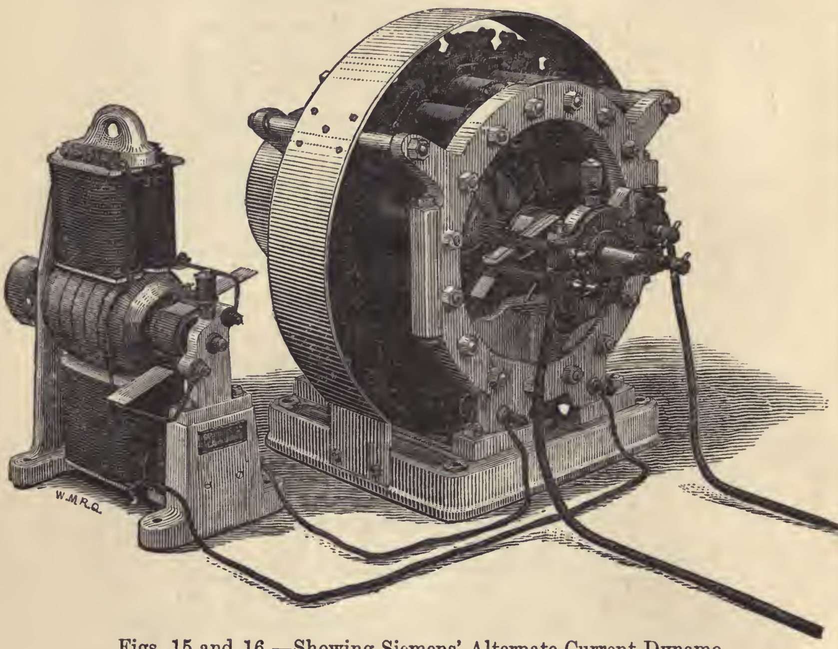
Fig. 14.—Characteristic Curve of Compound Wound Dynamo.

times in each second, the smallest number being 40, and the largest in present practice 133.

In each period, as it is termed, each complete series of reversals, the EMF passes from zero to a very much greater EMF than that which would correspond with the EMF that would do the same work, if furnished by a continuous current dynamo, thence back to zero. It

then furnishes an EMF in the opposite direction, the terminal that was positive now becoming negative, and *vice versâ*, to the same figure as in the first direction, then returns to zero and so on.

As would be shown by the curve, the rise and fall of



Figs. 15 and 16.—Showing Siemens' Alternate Current Dynamo, with its Excitor.

EMF are both gradual, the form of the curve being that which would be produced by the perpendicular to the horizontal, from various positions of the radius revolving round the centre, forming the curve of sines.

The working EMF is, as already explained, that which

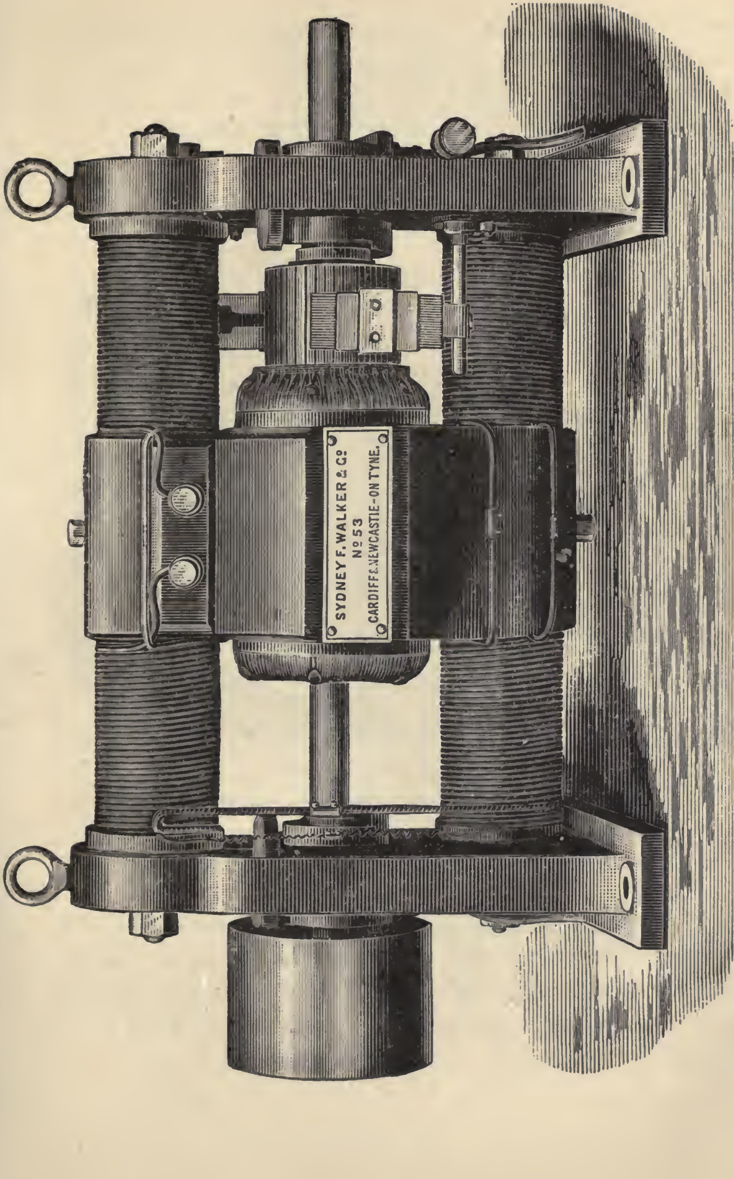


Fig. 17.—Showing Old Type of Gramme Continuous Current Dynamo.

is equivalent to the EMF that would generate the same heat in a conductor of a given dimension, if taken from a continuous current dynamo. This working EMF is found to be equal to the square root of the mean of the squares of all the EMF's generated.

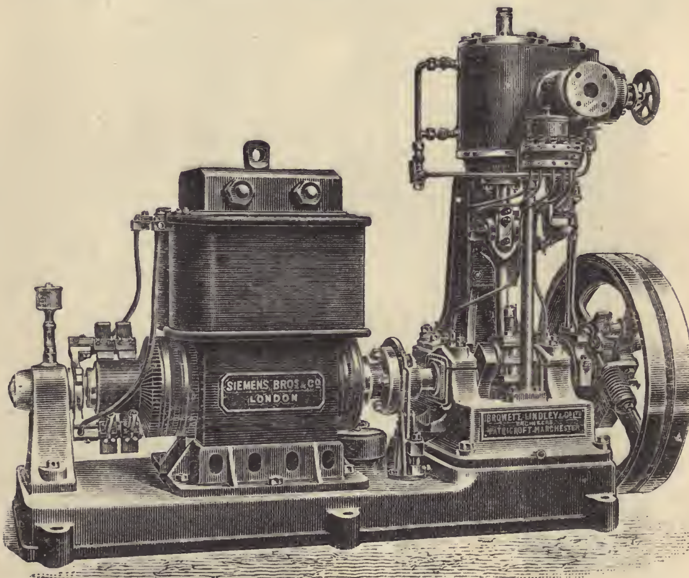


Fig. 18.—Latest form of Siemens' Dynamo, with Driving Engine.

Forms of Dynamos.

Fig. 15 shows the only form of alternator that has been used on board ship. It is of the Siemens pattern; having, as already explained, a double crown of short field-magnets with the starlike armature revolving in the space between them.

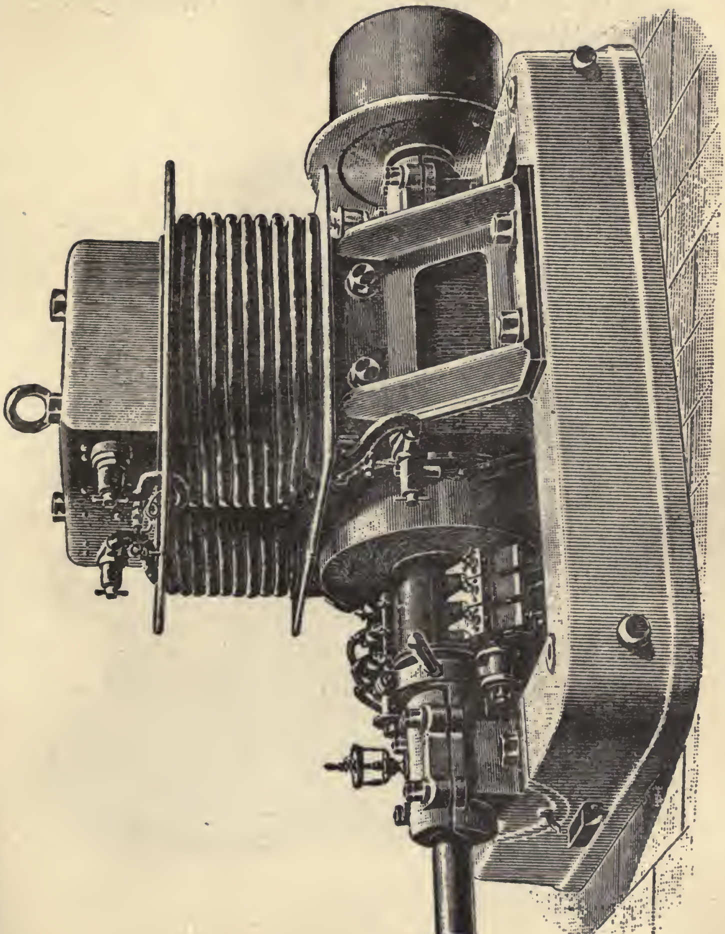


Fig. 19.

Fig. 16 shows the excitor, as it is termed, that is used with this dynamo. It is a series wound Siemens' dynamo of the early type.

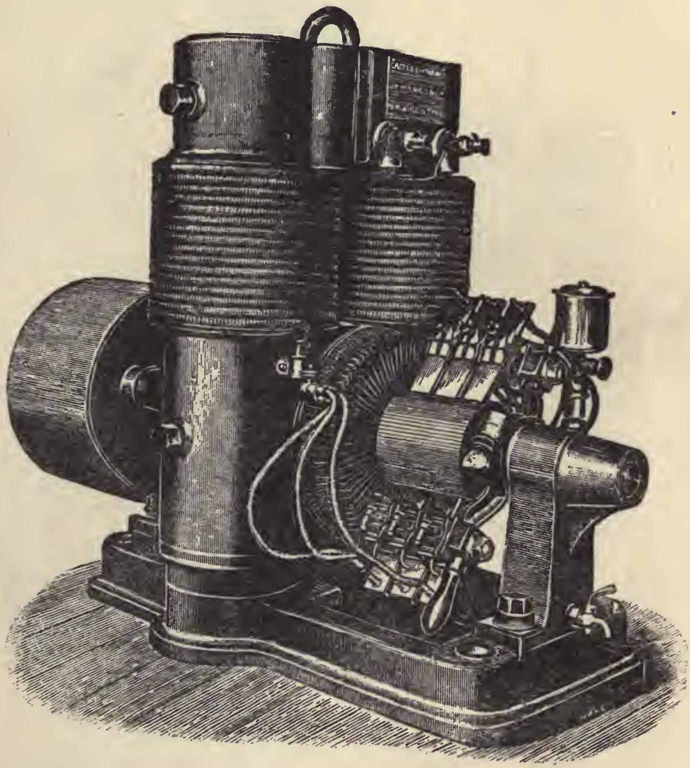


Fig. 20.

Fig. 17 shows the early type of Gramme machine, some of which may still be seen doing good work.

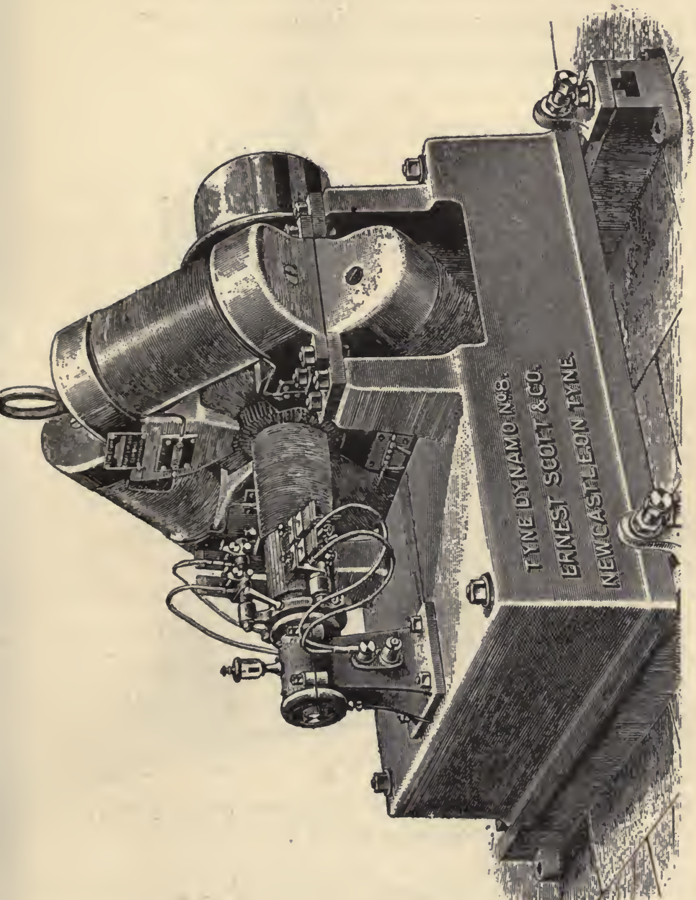


Fig. 21.

Fig. 18 shows the latest form of Siemens' dynamo, with its engine attached, on the same bedplate.

Fig. 19 shows the Siemens' dynamos that are now employed at central stations on shore.

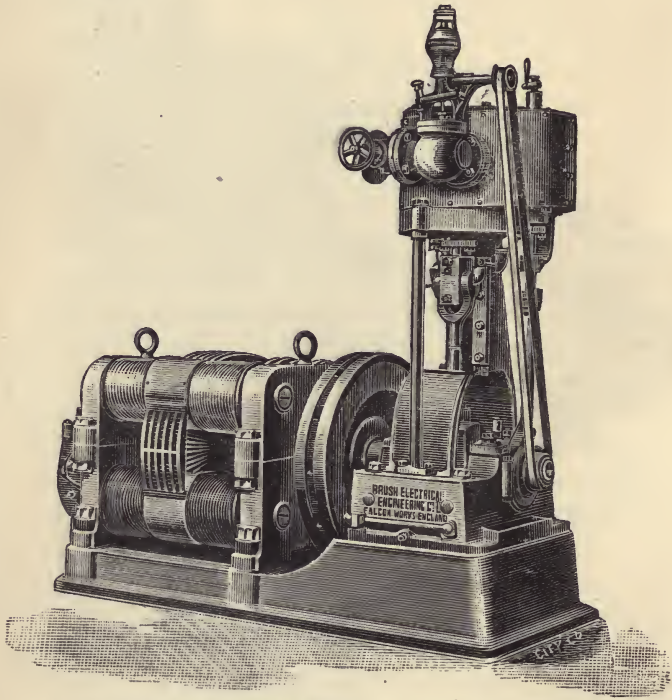


Fig. 22.—Showing Victoria-Brush Continuous Current Dynamo, with Engine attached.

Fig. 20 shows the Holmes' dynamo; Fig. 21 is one of Messrs. Scott and Mountain's War Office type Tyne dynamos; and Fig. 22 is the Victoria-Brush with engine.

The arrangement of these dynamos are all exactly alike, except those of the two last, the only difference between them being in the form of the field-magnets. Thus in the Crompton, early Siemens, and early Gramme, the field-magnets are of what are known as the double horse-shoe type, or double magnetic circuit type. That is to say, there are in each of these machines two complete horse-shoe electro-magnets, each having two legs, a yoke piece, which forms part of the frame of the machine, and two sets of wire coils for the electric currents that are to create the magnetism. In the Victoria Brush dynamo, and in the Scott and Mountain dynamo, four sets of magnets are used, with four sets of pole pieces, but only two sets of brushes; the coils at opposite ends of any diameter of the armature being connected together and so delivering their current to the same brushes.

In each of these machines the two horse-shoe magnets are joined by the polar extensions between which the armature revolves. In the Holmes and later Siemens' dynamos, the field-magnets consist of only two limbs, forming a single horse-shoe, having only one yoke and two magnetising coils, the pole pieces forming extensions of the magnet limbs, as in the double magnet type.

In the Holmes and Siemens' later dynamos the field-magnets are above the armature, while in the "Norwich" dynamo, another example of the same type, the pole pieces and armature are above the field-magnets.

In all but the early Gramme machine the axis of revolution of the armature is at right angles to a plane passing through the centre of the field-magnet limbs and yoke, the brush-gearing being carried by a brass ring, usually working on the outside of one bearing, and arranged to

revolve round the axle, as required to alter the lead of the brushes.

In the early Gramme machine the brush-gear is fixed to one of the side frames.

Looking after the Dynamo.

Starting.—See the bearings oiled, lubricators filled, everything clear of the armature, brushes carefully trimmed and set nicely on the commutator, so that they bear squarely right across its surface, all copper dust and oil carefully wiped off the pole pieces, standards, brush-gear, etc. Throw open all the main switches, then start the engine and run up to the proper speed. When the voltmeter shows that the proper EMF is being furnished, switch on your main circuits, one after the other.

The engine and dynamo should never be run without a governor.

Trimming and Setting the Brushes.—Whether these are made of gauze, plate, or wire, always cut them off quite square, and then file a slight bevel on the side that is to bear on the commutator.

Set the brushes in their shoes quite square, and see that each brush bears on the commutator for its whole width. See that the brushes bear sufficiently hard on the commutator to make good connection, but not too hard.

A guide will be, that pressure which wears both commutator and brush least, and which allows of least sparking.

Set the two brushes at exactly opposite ends of a diameter of the commutator. Some commutators have

their opposite segments marked. Where this is not done, they are easily found by counting.

In running, look out for the formation of what are termed "flats" on the commutator.

The sections of the commutator form sectors of a cylinder, and their surfaces are curved in proportion. They should retain their curve as they wear down. In some commutators, however, the ends of the segments which leave the brush last sometimes become flattened, the surface of the commutator then presenting an irregular curve. When "flats" are formed, sparking is increased at the brushes, and goes on increasing as the irregularity increases.

When "flats" are seen to be commencing to form, try to restore the circular form by filing, turning the armature slowly. If the trouble has gone too far to allow of being put right by means of a file, take a cut off the commutator the first opportunity, either in a lathe, or by means of a slide rest fitted to some part of the machine. The latter is by far the best plan, as it avoids the necessity of removing the armature every time. "Flats" generally arise from either badly regulated springs on the brushes, or from some of the segments of the commutator being a little harder than others. If the springs are not strong enough, the brush may jump lightly on leaving each segment, causing more sparking there than should be, with the result that that part of the segment is gradually worn more than the leading part, and so the circular sectional form is lost.

A *little* oil is occasionally of service in reducing both heating and sparking at the commutator, but it should be used *very* sparingly,—a drop on the tip of the finger,

applied to the surface of the commutator occasionally only.

The Lead of the Brushes.—This is of great importance to the sparking and to the wearing of the brushes and commutator.

All modern dynamos are made with their two brushes or sets of brushes, positive and negative, attached to a collar that can be revolved round the axis, an insulated handle being provided for the purpose.

The proper position for the brushes can always be found by turning the lever handle forward or backward in the direction of rotation, the right position being that at which sparking is least. This position varies with the work the machine is doing, or the number of lamps being taken from it. When only a few lamps are in use, the position of least sparking is not far from a line at right angles to the line joining the centres of the pole pieces. As lamps are turned on, or other work is done by the machine, the position of least sparking is moved farther and farther forward in the direction of rotation.

If a dynamo has been standing for some time, it may have temporarily lost its magnetism, and no current can be obtained from it.

Striking the pole pieces sharply with a mallet will sometimes remedy this. If not, get a battery of any kind and connect it to the shunt coils at the brushes, the positive pole of the battery being connected to the positive brush, and allow the current to pass for a few minutes, when the dynamo will usually be found to build up.

Other causes of failure and how to deal with them will be found in Chap. vii.

The Use of Accumulators on Board Ship and driving off the Main Engines.

The author has seen it gravely suggested that the electric light may be driven from the main engines, and that accumulators may be used to steady the light furnished by the combination.

A little thought will show any engineer that both ideas are utterly absurd, from a practical point of view. In the first place, what is required before all things to produce a steady light is a perfectly uniform speed at the dynamo, and as no set of main engines ever can be sure of accomplishing this at all times, it is evident that they are quite unsuitable for the work.

Slowing down, for instance, when going into harbour, the lights would go down when ploughing through a heavy sea-way. Again, the lights would go down, with the possible accompaniment of very bright intervals, when the screw was momentarily out of water and the engines racing.

But, it is suggested, "all that can be put right by using accumulators; they will absorb all the variations of the engines." Unfortunately, they will not. You may charge accumulators from a dynamo driven by the main engines, so long as the connection between the dynamo and the accumulator is broken instantly, if the speed of the dynamo falls below a certain figure, but lamps cannot be worked from the dynamo and accumulator combination without a special arrangement which adds to the apparatus to be looked after. Perhaps the following will explain both these facts:—

Each accumulator cell, when discharging, furnishing

current to the lamps, has an electro-motive force of 2 volts, so that for 60 volt lamps, 30 cells are required; 31 or 32 would usually be employed to allow for the resistance of the cells themselves, and for working down during discharge.

While the cells are being charged, and for a very short period after, each cell has an electro-motive force of $2\frac{1}{2}$ volts; so that, in order that a current may pass from the dynamo through the accumulator, the former must generate an EMF sufficient to overcome this counter EMF, and the resistance of the cells themselves, or about 82 or 83 volts.

Now, if the mains leading to the lamps are connected to the dynamo at the same time as the accumulator, the EMF will be very much too high and the lamps will be destroyed, unless a resistance is added to the lamp circuit, to reduce the voltage down to that of the lamps. But immediately you insert a resistance in the lamp circuit, you upset the regulation of your lamps, unless you make your mains larger in proportion, so as to allow for this.

Again, if from *any* cause, the EMF at the terminals of the dynamo falls below that necessary to drive a current through the accumulators, the latter will discharge through the dynamo.

So that, unless the charging was very carefully watched, and the accumulators instantly disconnected, when the engines slowed or the belt slipped, it would probably be found, at the end of a long run, that the power had all been wasted, the accumulators having little or no charge in them.

Besides the above, accumulators would be sure to give trouble on board ship. However carefully the trays

holding the cells were hung, the acid would spill at times when the ship pitched or rolled heavily, and there is quite enough to do on board ship, with the unavoidable presence of salt spray, without adding sulphuric acid.

It will be a different matter when, if ever the time comes, the ship itself is driven by a dynamo instead of an engine, with accumulators in place of boilers.

For harbour work, too, it is surely better to use steam from the donkey-boiler than to have the trouble of an accumulator.

CHAPTER III.

CABLES AND BRANCH WIRES.

WE come now to the consideration of the cables and branch wires used to connect the dynamo, where the current is generated, with the lamps where it is used.

The size of these is ruled principally by the same law, Ohm's, that has so often been referred to.

Perhaps a better illustration of the working of this law is the behaviour of incandescent lamps themselves as their life increases. Each lamp, whether it be of 8 candle-power, 16 candle-power, 50 candle-power, or upwards, to 1500 candle-power, requires a certain current passing through it, in order to enable it to give out its proper light. When first made, each lamp has a certain resistance when burning, which is so proportioned that on the application to its terminals of the EMF for which it is constructed—say 65 volts, 80 volts, etc.—the proper current passes that is required to give out its number of candle-power light. As the lamp burns, however, as those who have used the electric light will have noticed, the bulbs of the incandescent lamps become dark, owing to a deposit of carbon from the filament, the hair-like conductor inside, upon the interior of the glasses. As this carbon is taken from the substance of the filament itself, the sectional area of the latter, its thickness

decreases as the deposit goes on, and its electrical resistance increases in about the same proportion, with the result that less and less current passes through the lamp, causing it to give out feebler and feebler light. All of these cases are ruled by Ohm's law, and so is every electric circuit and every path by which the current can pass, even though it be not a legitimate path, and one that is doing harm instead of good. As will easily be understood, though there must be a complete path for the current before it will pass, there may be any number of such paths. And, in practice, the distribution of current for electric light on board ship resolves itself into connecting two conductors to the two terminals of the dynamo, and bridging across between these by smaller conductors in which the lamps are included, as shown in Fig. 23. As distribution may have to be effected in different quarters, branch cables are connected to the mains leading from the dynamo, and lamps bridged across these by means of smaller wires again. Fig. 23 shows a pair of mains with two branches, all carrying lamps, and Fig. 24 a larger set, with secondary branches leading out of the first. In practice the conductors for distribution of electric currents for lighting are laid out much in the same manner that steam or gas pipes are. You start with large pipes or mains, to these you join smaller ones, to those again smaller ones, and so on; the pipes or mains becoming smaller as the current they have to carry becomes less. The difference between electrical distribution and that of gas, steam, or water, is that whereas with the latter the fluid is allowed simply to escape more or less directly, after doing its work, either into the atmosphere, the ground, or some

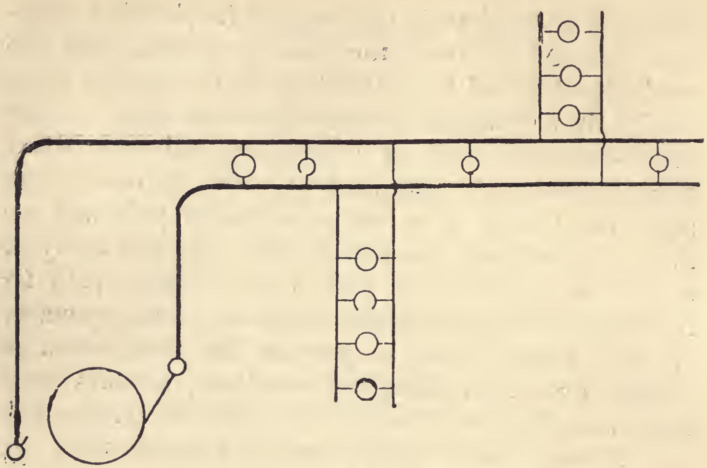


Fig. 23.—Diagram of Connections between Dynamo, Cables, and Lamps.

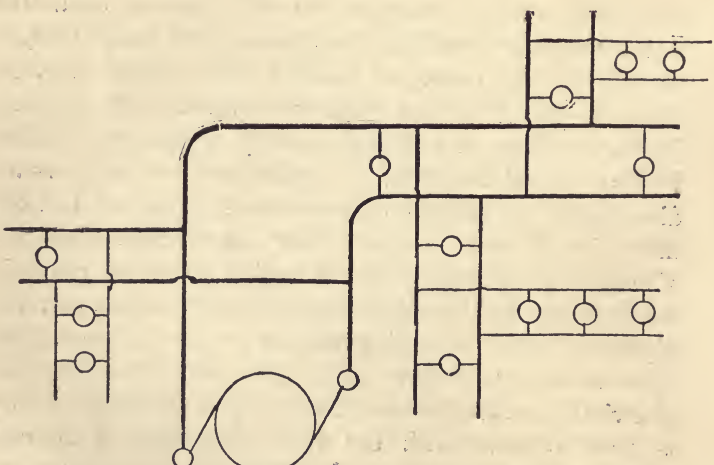


Fig. 24.—Diagram showing Connections between Dynamo, Cables, and Lamps.

receptacle provided for it; with the electric current a *path must be made for it back to its generator*, or the apparatus it is designed to operate will not work.

The size of the cables for distribution is governed by two requirements: first, the heating effect; and secondly, the fall of EMF due to the passage of the current through the conductor. As already mentioned, the passage of an electric current through any conductor generates heat in the latter in proportion to the square of the current strength $\times$ the resistance of the conductor $\times$ the time, or $H = C^2Rt$. Thus it will be seen that the higher the resistance of a conductor through which a given current is passing, the greater is the heat generated. In the case of distribution for electric light on board ship, this means that the smaller the conductor the hotter it gets with a given current. The formula also shows that the heating effect increases very rapidly as the current increases, with a given resistance, and for this reason it is better to allow a good margin over and above the size required for the ordinary current strength, so as to provide for an accidental increase of current. Two other points that should be noted in connection with the heating effect are the time factor in the equation, and the condition of the surrounding atmosphere. For regular lighting, for hours together, a larger margin should be allowed in the size of the cables, than where the current is only in them for a short time. So, too, cables in which the full current is always on during lighting hours should be larger in proportion, than those in which a portion of the lights supplied by that cable are turned off for a portion of the time. The case where lamps are burning day and night, of course, requires the most liberal treat-

ment on this account. The condition of the surrounding atmosphere, it has been already pointed out, should also be taken into account in the size of cables required for any particular work. The cable leading to the masthead light, for instance, open to the free action of the wind, will safely carry a considerably higher current than a similar cable laid in the stockhold or the engine-room; and the reason, which is familiar to marine engineers, is the same that was given in connection with the explanation of the action of the alternate current machine, viz. the temperature which any body assumes under the influence of a source of heat, is a balance between the heat received from the source and that given off by radiation and convection. In the close atmosphere of the stockhold, or the engine-room, the loss of heat from these causes will be small compared to that in the open air, exposed to every wind, rain, etc., so that the temperature will rise much more in the former place than in the latter, with a given current strength, and therefore a larger margin must be allowed.

Of course, it is hardly to be expected that a marine engineer, with all the engines of the ship under his charge, will have time to make an elaborate calculation, taking into consideration all the points enumerated, so that some rough and ready rule is required for guidance.

The insurance companies' rule is that not more than 1000 ampères to the square inch shall be allowed under all circumstances. It is obvious, however, that this must be capable of considerable modification. Small wires, for instance, have a far larger radiating surface than large

ones, and can be safely entrusted with larger proportionate currents.

Take, for instance, a conductor an inch square, and, therefore, of a square inch sectional area, and compare it with a No. 20 standard wire gauge wire. The □″ rod has a surface of 4 inches for radiation; the No. 20 wire, whose sectional area is $\frac{1}{1000}$ that of the □″ rod, has a surface of $\frac{1}{40}$ inch, or its radiating surface is only $\frac{1}{40}$ that of the inch rod, and should therefore be allowed to carry 25 ampères instead of only 1. Practice, however, has determined these matters, and, as usual, before theory entered the field, and the table on the following page shows the figures.

The figures given represent the currents that the respective wires should safely carry, and the lamps they should feed under the most unfavourable circumstances. In a great many cases larger currents are allowed. For instance, 7 No. 18 wires is often allowed to carry 20 ampères, and 7 No. 16 wires 40 ampères. Cables are made of a number of wires stranded together, as 7 No. 16's, 19 No. 20's, and so on, in order that they may be more flexible than the solid wire of the same sectional area, and because indiarubber and other substances are more easily laid upon a stranded wire, when the cable is of a certain size, than upon a solid wire. In laying cables it is of very great importance to have them as flexible as possible, especially on board ship, where they may have to be bent round sharp corners. The plan of stranding a number of wires together achieves this result in a remarkable degree, but it presents the disadvantage that if salt water does reach the conductor it acts upon the surfaces of the whole of the wires at once, causing

TABLE OF WIRES FOR USE WITH INCANDESCENT LAMPS.

SAFE NUMBER OF LAMPS FOR EACH CABLE.

Standard Wire Gauge.	Sectional Area in square inches.	Resistance of 1000 yards.	Resistance of 1 mile.	60 Volt 16 c.-p. Lamps.	60 Volt 32 c.-p. Lamps.	60 Volt 50 c.-p. Lamps.	60 Volt 100 c.-p. Lamps.	60 Volt 200 c.-p. Lamps.	80 Volt 16 c.-p. Lamps.	80 Volt 32 c.-p. Lamps.	80 Volt 50 c.-p. Lamps.	80 Volt 100 c.-p. Lamps.	80 Volt 200 c.-p. Lamps.	100 Volt 16 c.-p. Lamps.	100 Volt 32 c.-p. Lamps.	100 Volt 50 c.-p. Lamps.	100 Volt 100 c.-p. Lamps.	100 Volt 200 c.-p. Lamps.	Remarks.
$\frac{1}{20}$	·0010	24· Ohms	43·9 Ohms	1	0	0	0	0	1	0	0	0	0						The number of lamps in each case is calculated not to allow more than 1000 ampères per square inch to pass through the cable. Cables are made between the sizes given, such as $\frac{7}{21}$, $\frac{7}{17}$, $\frac{19}{19}$, $\frac{19}{15}$, and so on, the lamps for which can easily be seen by inspection.
$\frac{1}{18}$	·0018	13·5 ,,	24·6 ,,	1	0	0	0	0	2	1	0	0	0	1	0	0	0	0	
$\frac{1}{16}$	·0032	7·6 ,,	13·9 ,,	3	1	1	0	0	4	2	1	0	0	3	1	1	0	0	
$\frac{7}{22}$	·0043	5·7 ,,	16·2 ,,	4	2	1	0	0	5	2	1	0	0	5	2	1	0	0	
$\frac{1}{14}$	·0050	4·9 ,,	8·9 ,,	5	2	1	0	0	6	3	2	1	0	7	3	2	1	0	
$\frac{1}{13}$	·0066	4·0 ,,	6·7 ,,	6	3	2	1	0	8	4	2	1	0	8	4	2	1	0	
$\frac{7}{20}$	·0071	3·45 ,,	6·17 ,,	7	3	2	1	0	9	4	3	1	0	11	5	3	1	0	
$\frac{1}{12}$	·0085	2·88 ,,	5·25 ,,	8	4	2	1	0	11	5	3	1	0	11	5	3	1	0	
$\frac{1}{11}$	·0106	2·4 ,,	4·22 ,,	10	5	3	1	0	14	7	4	2	1	14	7	4	2	1	
$\frac{7}{18}$	·0127	1·97 ,,	3·47 ,,	12	6	4	2	1	17	8	5	2	1	17	8	5	2	1	
$\frac{1}{10}$	·0129	1·9 ,,	3·4 ,,	12	6	4	2	1	17	8	5	2	1	21	10	7	3	1	
$\frac{19}{20}$	·0194	1·27 ,,	2·26 ,,	19	9	6	3	1	26	13	8	4	2	32	16	10	5	2	
$\frac{7}{16}$	·0225	1·11 ,,	1·95 ,,	22	11	7	3	1	30	15	10	5	2	37	18	12	6	3	
$\frac{19}{18}$	·0344	0·88 ,,	1·27 ,,	34	17	11	5	2	40	20	13	6	3	57	28	19	9	4	
$\frac{7}{14}$	·0352	0·84 ,,	1·25 ,,	35	17	11	5	2	40	20	13	6	3	58	29	19	9	4	
$\frac{19}{16}$	·0612	0·40 ,,	0·71 ,,	61	30	20	10	5	80	40	26	13	6	102	51	34	17	8	
$\frac{19}{14}$	·0956	0·26 ,,	0·46 ,,	95	47	31	15	7	129	64	43	21	10	159	79	53	26	13	

the cable to be parted in a very much shorter time than would otherwise be the case. As an instance of the value of flexibility in a cable, the writer recently laid a pair of cables, each consisting of 37 No. 16 wires stranded together, the whole being thickly covered with insulating material, in the shaft of a coal mine 400 yards deep. Had it been a solid rod of the same weight and sectional area, it would have been a most difficult undertaking, and could not possibly have been accomplished without numerous joints, each causing a loss of EMF, owing to the increased resistance introduced. With the stranded cable the whole was laid in one length, and with no greater difficulty than is unavoidable when working in a coal mine.

The other factor governing the size of the cables, that of the loss of EMF due to the charge for the passage of the current through the resistance offered by the cable, will not often materially affect their size on board ship, the distances usually not being great. As there may be cases, however, where a number of lamps, or one or two large lamps, are required at a distance from the dynamo, it will be as well to give the rule. It will be remembered that in Ohm's law we have the formula $C = \frac{E}{R}$, where C = current strength in ampères, E the electro-motive force in volts, R the resistance in ohms. The formula may be written $E = CR$ and thence $R = \frac{E}{C}$, which is the form in which we use it for calculating the size of the cables required. And it is used in this way:—Determine the number of volts' drop that may be allowed between the terminals of the dynamo, and the end of the cable whose

size we are calculating, the current which has to be delivered at its farther end, divide one by the other, and the result is the resistance of the *pair of cables* required. Every manufacturer's list or table of resistances gives the resistance of each cable, usually per mile and per 1000 yards, and they are given in the table on page 80. Suppose, for instance, it be required to calculate the size of cables to convey the current from the dynamo to the neighbourhood of the saloon. Take the distance at 50 yards, the number of lamps 50, and the initial voltage at the terminals of the dynamo as 60 volts. The current required for 50 lamps of 16 candle-power, whose EMF is 60 volts, is 50 ampères. The total loss that can be allowed between the dynamo and the farthest lamp should not be more than 3 volts, for reasons that will be explained later on; therefore, only 2 volts at most can be allowed to the entrance of the saloon, or the point from which branches are to be taken for groups or individual lamps.

Applying the formula $R = \frac{E}{C} \therefore R = \frac{2}{50} = \frac{1}{25}$ ohm for 100 yards of cable, equals $\frac{10}{25}$ for 1000 yards $= \cdot 4 = 19$ No. 16 wires.

If only 1 volt could have been allowed, the resistance of the two cables would have been ·2, or the cable would have been double the size.

But now, as to how to determine what loss of voltage may be allowed in any pair of cables. The problem here is very analogous to that of the loss of pressure that may be allowed in a steam-pipe, between the boiler and the engine or pump it may have to work. The loss allowable is determined by the fact that the pressure or

voltage at the point of consumption must be sufficient to do the work under all the conditions that may rule at different times.

First, the voltage must be sufficient at the terminals of each individual lamp to give the proper light when all other lamps are in use; and, secondly, there must not be a serious increase of current and of light when other lamps are turned out. If, for instance, the loss of voltage to the point of distribution near the saloon had been taken at 10 volts, in place of 2 volts, as given above, either the voltage at the dynamo must have been 70 volts, to allow of the lamps in the saloon being at 59 volts or 60 volts pressure, or the voltage of the lamps in the saloon must have been 50 volts instead of 60 volts, the latter being the voltage at the terminals of the dynamo. A 60-volt lamp, burning with only 50 volts at its terminals, would not give two-thirds of its proper light, as the incandescence of the carbon filament increases and decreases very rapidly, with the rise and fall of the voltage. Therefore, a 50-volt lamp would require to be used if a drop of 10 volts was allowed, and the voltage at the dynamo was 60. Now if, say, half the lights were turned out, the voltage at the terminals of those left burning would rise to 55 volts, which would seriously strain the filament and shorten the life of the lamp. Further, if only a few lamps were left burning for some time—say, during the night—these would be giving a very bright light, and would be burning at 58 or 59 volts in place of 50 volts, wearing themselves out very rapidly.

For such work as lighting the saloon of a steamship, not more than 5 per cent. of the voltage at the dynamo

should be lost in the cables between it and the farthest lamp, otherwise there is too large a variation in the light given by individual lamps, and the lamps themselves are strained when burning at the higher voltages, and by the variation itself. Where a number of lamps are required to be all in use at once, or all out of use at once, of course a larger drop in the voltage may be allowed, if any advantage is gained in the size of the cable; but this can only be the case where a comparatively large number of lamps are in use at a distance from the dynamo. Even where such a case does occur it is well to remember that the loss in voltage in the smaller cable, is also a waste of the power developed by the engine driving the dynamo. In the case given, for instance, the loss in the cables between the dynamo and the saloon, with 2 volts drop, is $2 \times 50 = 100$ watts, or $\frac{100}{746}$ horse-power. With 10 volts drop, it equals 500 watts, giving in the first case less than $\frac{1}{7}$ horse-power, and in the second about $\frac{2}{3}$ horse-power. As explained at p. 7, the actual waste in the power developed by the engine would be more than these figures; the waste in the cables having to bear their share of losses due to friction, magnetising the dynamo, etc.

In a large number of steamers advantage has been taken of the fact that the skin of the ship is itself a conductor, and is surrounded by water, which is also a good conductor when in a large mass, to save one of the cables. The plan adopted is to connect one terminal of the dynamo to some part of the framework of the ship, and lead out only one cable to all the lamps; one terminal of the lamp being connected to the skin or framework of the ship also. The connections in this case are

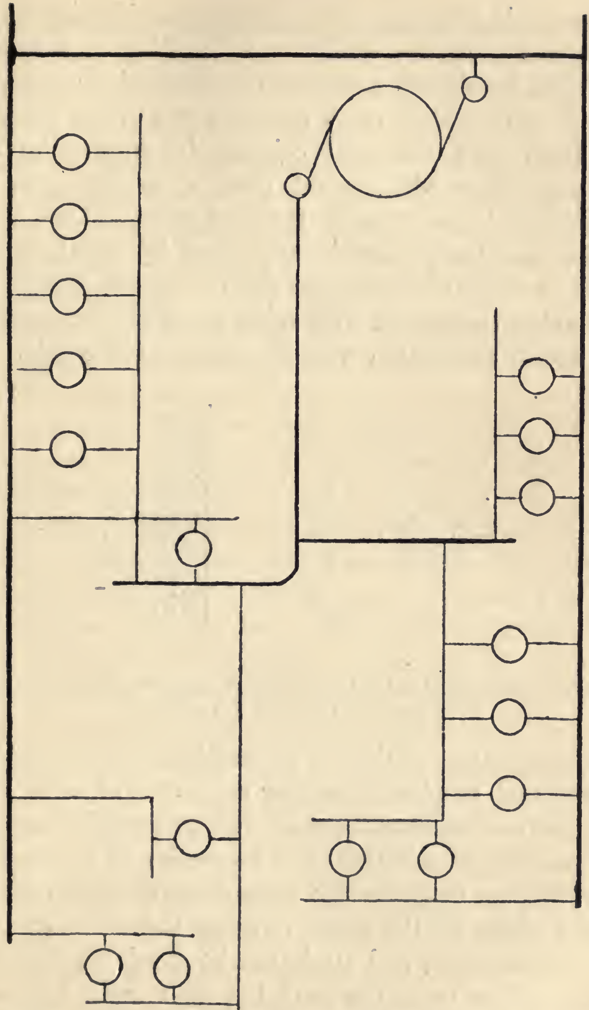


Fig. 25.—Diagram of Connections between Dynamo, Cables, and Lamps, using the Skin and Body of the Ship as Return.

as shown in Fig. 25. The principal objection to this arrangement is the difficulty of getting a connection that shall be always good between the mains or branches and the ship. Care must be taken not to use pipes that are fitted with indiarubber joints for connecting to, as the connection will depend then upon the iron bolts making good contact with the iron pipes. Also, no part of the machinery that is supported by wood or other insulator should be used for the connection unless it is in metallic connection with other parts of the machinery that are in connection with the frame of the ship. The

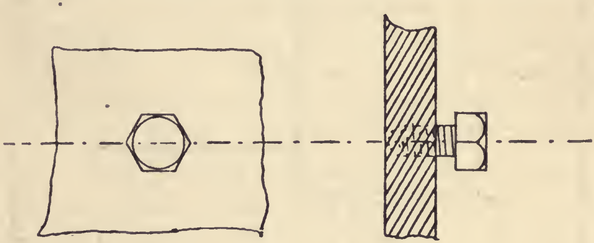


Fig. 26.—Diagram showing the Method of connecting Branch Wires to the skin of the Ship, Beams, etc.

only practicable method of connection to the ship, is by drilling and tapping a hole for each wire or cable that is to be connected, allowing the screw to have a long thread in the metal into which it is screwed, and a broad head with a flange large enough to comfortably grasp the wire, or the whole of the wires forming the cable, all round its circumference, and to have the head firmly screwed down. Be sure to see that the screw-head has a firm grip of the whole of the wires of the cable; and, in case of trouble with any of the lights, examine all of these

screwed connections that form parts of the circuits in which the failing lamps are. Where soldering or brazing can be effected, it should be done. The great danger to be feared with the connections to the skin of the ship is the possibility that the working of the ship may loosen the screw, allowing moisture to penetrate, with its attendant rust. Iron rust offers a high resistance to the passage of the current; and, further, iron and copper, with moisture present, form a galvanic battery in themselves, with the result that the iron is caused to rust more than it otherwise would do, gradually building up a barrier to the passage of the current; the very building up of the rusty barrier being assisted by the lighting current itself where the positive terminal of the dynamo is connected to the ship, and the current passes from the iron to the copper-wire. If the negative pole of the dynamo is connected to the ship, so that the current passes from the copper to the iron, the former will be eaten away, in spite of the protecting value of the iron. Unfortunately, too, the ordinary methods that are used to protect iron from rust are not permissible here. Oxides of lead and other salts, of which paints are composed, are very poor conductors; so also are grease, oils, etc. In fact, it is one of the first rules to be remembered in connecting two metals together, so that an electric current may pass through the joint with the least possible resistance, that all paint, grease, dirt, etc., must be removed from both surfaces, leaving very clean, bright metals in close contact with each other.

Another point that may be useful to remember is, that whenever two substances combine together, as in the case of metals with oxygen to form oxides, or two

metals together, as in an alloy, the electrical resistance offered by the compound, in whatever form it may be, is much higher than that of either of its components. Thus, even a brazed joint has a resistance higher than the dimensions of the two metals it joins would have indicated. The presence of a very small percentage of foreign matter, such as arsenic in copper, increases its resistance 50 per cent. In fact, the electrical resistance of a wire of a given length and cross section, drawn from a particular ingot of copper or other metal is one of the tests, and probably the best test, of its purity.

The other objection to using the skin of the ship as a return conductor will be dealt with more fully in connection with the insulation of the cables. The advantages of using the skin of the ship as a return are—the saving of one cable, and the greater neatness and simplicity of the arrangement.

Then, as to what the cables shall be composed of, and how they shall be fixed. They are, of course, composed of copper wires covered with insulating material; the object of the latter being to prevent any current from passing from one cable to the other except through the lamps, and only through them when they are in use.

In practice it is not possible, without incurring very heavy expense, to prevent any current passing otherwise than through the lamps. Even with the highest insulation obtainable, a small current always passes *through the insulation*, whatever it may be; and the most that can be done, therefore, is to reduce the leakage current, as it is termed, as much as possible. Breaking the insulating envelope to connect branch wires always gives rise to leakage, however carefully the joint may be made,

therefore joints are to be avoided as much as possible. Leakage also takes place across switches, lamp-holders, etc., as will be explained in dealing with fittings for the lamps. The cables must, of course, be so laid and so fixed that the copper is not only insulated when first fixed, but for years afterwards. And here comes in one of the difficulties of electric lighting on board ship. Salt water, or its deposit, penetrates everywhere on board ship, no matter what precautions are taken, and salt is often a bad friend to insulating materials. Moreover, between decks, where cables are run, more particularly in hot climates, moisture condenses, and damp of any kind is bad for insulation. Further, every ship works in a seaway. Her beams, bulkheads, decks, sides—every part of her in fact—is on the move with the rolling and pitching, as well as with the constant vibration from the main engines. Again, a ship is exposed to very wide changes of temperature; now intensely cold, and in a few days as intensely hot; now running down the roaring forties, possibly on the way to Australia, then baked up in the Red Sea, or going up the Hooghly. If the electric light is to be successfully applied, the cables must be so constructed as to stand all these. Shipping any number of green seas in the Bay of Biscay must not affect the insulation, even if the cables, or any portion of them, have to remain under water for some time; nor must a week or a month's lying at anchor in some tropical port, in the middle of the rainy season. Neither the vibration of the main engines nor the working of the ship, even in a gale, must develop cracks that will let the water in, or cause breaks between main and branch cables. How is this to be accomplished? Three sub-

stances have been employed, principally for insulating wires and cables—guttapercha, indiarubber, and a compound of pitch known as Callender's core. During recent years, too, cables have been insulated by drawing the bare copper into lead pipes, and filling the space between the copper and the lead with cotton or yarn steeped in a preservative or insulating compound. Indiarubber and Callender's cables have also been protected outside the insulation with an armour of iron wires, as the ocean submarine cables are, and by being drawn into lead pipes.

Of the different substances named, indiarubber is the most suitable for shipwork, as neither guttapercha nor Callender's core will stand heat, as ships get it in the tropics between decks. Guttapercha, too, has the failing, that unless a good thickness is provided, the copper, if at all heavy, may work through it. Callender's core is the cheapest form of insulation, and is being largely used for numbers of electric light installations on shore, even where the cables are buried underground in the streets, and is answering well, provided due precautions are taken to protect the insulation. It would be suitable for ships not going to the tropics, and where the cable could be kept out of the hot parts of the ship. Guttapercha is the only material that will stand wet continually, by itself, but it will not stand being alternately wet and dry, nor exposure to the light, especially the powerful tropical sunlight, and wet will even find its way through guttapercha if it be thin. Guttapercha, also, is not so elastic as indiarubber, and will, therefore, be much more liable to crack under the strains it will be subject to on board ship. Indiarubber does not

withstand wet or grease for long, no matter how much it may be vulcanised. In the writer's opinion, therefore, indiarubber, a good thickness of it, protected by a good serving of tarred rope yarn, is the most suitable for the insulation of electric light cables on board ship. The spun-yarn covering should be two layers deep, and may be overlaid with a couple of wrappings of tape soaked in some so-called waterproof composition. This covering protects the insulation both from the wet and from mechanical injury. The latter is, as will easily be understood, another very important point in connection with cables for ship lighting by electricity. Cables have to be fixed between decks, and, under the most favourable conditions, they are liable to be knocked. They are also liable to be cut, or the insulation worked through, where they pass under beams, over the sharp edges of iron plates, etc.; and once the insulation is damaged—leaving the copper wires exposed — moisture will be sure to penetrate, and begin to eat the wires away on the one hand; and, on the other, there will always be a danger of the exposed portion of the cable coming into contact with some conductor which is in connection with the other cable, causing sparking, with all its attendant troubles.

This danger of sparking is especially to be feared where the skin of the ship is used as a return—as, no matter where the cable is rubbed through, with iron or steel-built ships, it finds the other side of the circuit at once in the metal edge which has destroyed its insulation. Where two cables are used it needs two of these connections to make a fault, and to give rise to a spark. If one cable rubs its insulation through on the sharp edge

of a beam it does no harm, unless the other cable does the same. The writer understands that armoured cables —cables protected with a covering of galvanised iron wires—have been recommended and used on board ship. In his opinion they are not sufficiently flexible. They do not give to the workings of the ship, and there is very great danger that the insulating substance will suffer. As something must give way, and the insulating material is always the weakest, mechanically, it will proverbially go to the wall. Drawing the insulated cable into a lead pipe is also not to be recommended, however carefully it may be done. One can never be certain that the insulating coating has not been damaged in the process of drawing it through the lead pipe; and in many instances where this form of cable has been used, though it has tested well at first, it has broken down after, and caused considerable trouble. Especially will this be so where the skin of the ship is used as a return; as, the lead covering of the cable being directly in connection with it, the full voltage of the machine is in tension, between the copper and the lead; and, should there be any flaw in the insulating envelope, either due to defects in the manufacture, or to damage during the process of hauling it through the tube, the insulation will gradually give way at that point, sparks will pass between the copper and the lead, melting the latter, and doing a considerable amount of other damage.

It may be here mentioned that another reason, in the writer's opinion, for not using the skin of the ship and for having the insulation as high as possible, is the fact that the insulating covering, whatever it may be, deteriorates more or less slowly under the influence of the

minute current which passes through it. It will be remembered that it was pointed out in an earlier part of the book, that Ohm's law ruled absolutely what current should pass under all conditions. This applies to insulation resistances as well as to what are called conductive resistances. If the voltage be only 50 or 100 volts, while the resistance opposed to it is many hundreds or thousands of millions of ohms, so that the product of the equation $C = \frac{E}{R}$ is a fraction so minute as to be almost beyond our powers of conception, and quite beyond our powers of measurement with our present apparatus; yet that fraction, say a millionth or a ten-millionth of an ampère, will pass and will do the work of a millionth or ten-millionth of an ampère upon the insulating substance it passes through. One of the most important properties of the electric current is what is known as electrolysis, the power of splitting up compound substances, delivering the gases of the composition — with the exception of hydrogen—where it enters the substance, and the metals and hydrogen gas, where it leaves it. Other numerous chemical and electro-chemical reactions follow, but the result is always the same. At some period, depending upon the proportion between the insulation resistance and the EMF opposed to it, the former breaks down at some weak point, and a spark passes across. Wet and heat, in their different ways and by their different actions upon substances of different nature, aid this process—more particularly wet.

As it will easily be understood that the more moisture penetrates into the substance the greater the capacity of any current for giving trouble, and usually the greater

the current passing; as the presence of water, in nearly all cases, reduces the insulation resistance, and thereby increases the current strength. Nearly all the fires that were caused by electric currents in the early days of electric lighting could be traced to low initial insulation resistance, lowered, often considerably, by damp.

Arrangement of Circuits.

The dynamo and engine being usually placed near the middle of the ship, it follows, almost as a matter of course, that separate pairs of cables are taken out from it, one pair for the forecastle and the forepart of the ship generally, a second pair for the afterpart, a third pair for the holds, a fourth pair for the engine-room and stokehold. In large passenger ships, two or more circuits are usually taken to each saloon, so that all the lights in the saloon may not be out at the same time.

In large passenger ships, too, it is usual to have at least two dynamos and engines for the electric lighting service, and in some of the largest ships three dynamos and engines, two working and one spare.

The various pairs of cables are not brought directly to the dynamos, but to a switchboard placed near the dynamo, on which also are placed the measuring instruments, one voltmeter for each dynamo, and one ampère meter for each pair of mains. On this switchboard are placed the main switches which connect the various pairs of main cables with the dynamos, and either the fusible cut-outs, or electro-magnetic cut-outs, that are used to protect the different circuits and the dynamos in case of accident.

Figs 27 and 28 show switchboards suitable for use on board ship. Fig. 27 shows the usual arrangement of cirouits on board a "tramp."

It will be understood, of course, that there should be an ampère meter on each circuit, so that the engineer can see what is going on. This, however, is not always

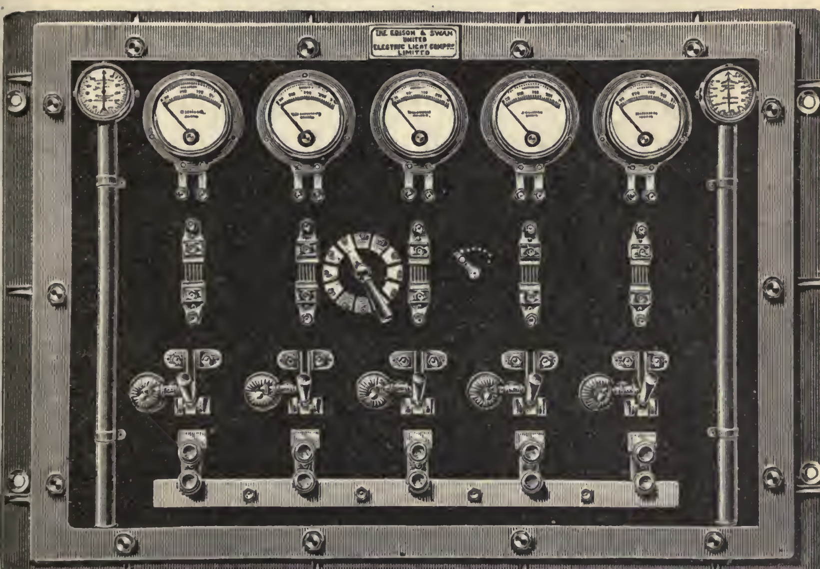


Fig. 27.

done. In many "tramps" not even one ampère meter is to be found.

The method employed in fixing the cables has a very material influence on the life of the cables, and also upon the amount of trouble they will give. Both on shore and on board ship cables and branch wires are

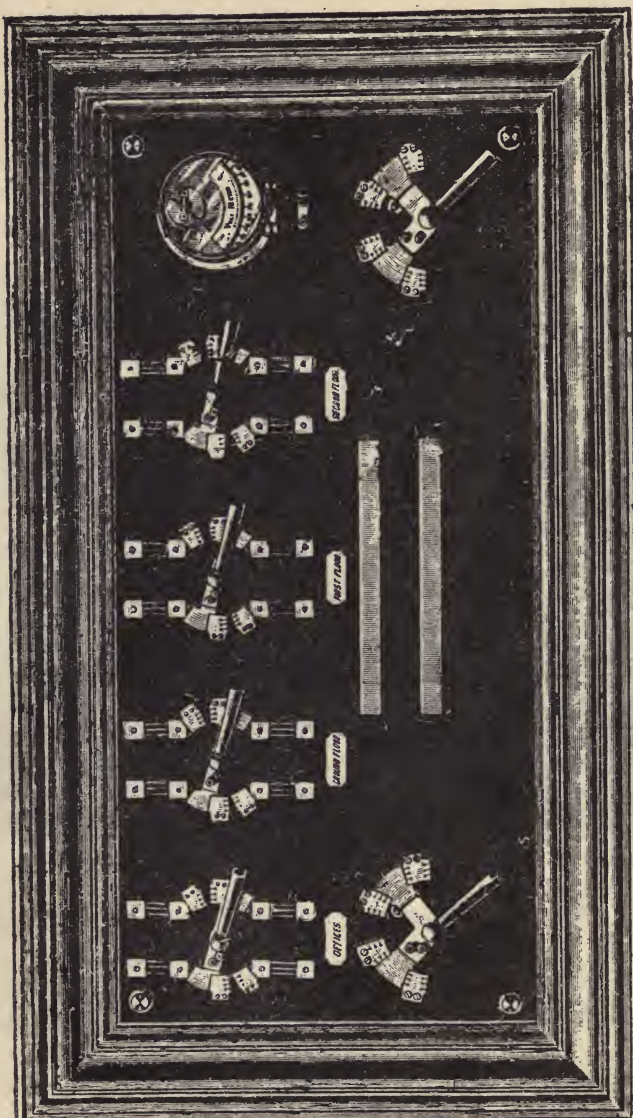


Fig. 28.—Showing a Switchboard for use with two Dynamos.

now always laid in grooved casing of the pattern shown in Fig. 29. The casing consists simply of a strip of wood of the required thickness, having two grooves cut in it of sufficient size to take the wire that is to be used with it. The two grooves must not be less than half an inch apart, for the smallest wires, and the intervening piece is used to secure the casing in position. A light lath is also provided to cover the boarding when the wires are in. The cover is secured to the casing by screws or nails in the centre piece. It may be made ornamental, gilded to form a decoration, or quite plain.

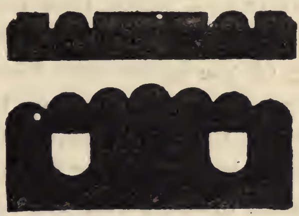


Fig. 29.—Section of Grooved Casing used for Electric Light Cables.

The grooves are best made just to hold the wires, a light tap being required to send them into their place; and they should be deep enough to allow the wires to be below the edge of the groove when in their places, so that the rubber and braid covering may not be damaged in putting on the cover of the casing. Where the groove is larger than the covered wire, the latter should be held in its place by wooden pegs fitting firmly into the groove but not crushing the wire. The object of the grooved casing is primarily to protect the covering of the wire from mechanical injury; as it is evident that the casing itself must be destroyed, if it is properly laid,

before any injury can come to the cable inside it. Unfortunately, however, grooved casing itself has sometimes developed faults, as it harbours moisture; and the writer has known engineers who have stated that the best plan was not to protect the wire, but to let it take its chance.

The reason for this opinion being formed is that cases have occurred where cables, having been laid in casing in damp places, the casing has absorbed moisture, which being always present round the cable, has deteriorated its insulating covering; the latter has gradually broken down, a spark has passed across from cable to cable, and trouble has followed. In most of these cases the insulating covering of the cable itself has been defective, and therefore presented an easy prey to the moisture; and a great many of the faults have occurred at joints, where the insulation is unavoidably damaged. It is quite practicable, however, to secure all the advantages of the mechanical protection of the grooved boarding, without much risk of the other consequences, provided the work be carefully done.

In order to guard against the possibility of the insidious action of moisture always present in the pores of the wood casing, the latter should be filled with an insulating substance. Many of the Electric Lighting Companies in this country insist that the grooved casing shall be coated with shellac varnish; and if this is properly done, moisture cannot get a lodging in the pores of the wood, until it has first displaced the shellac. But the varnishing must be thorough. It is not sufficient to put a few grains of shellac in a large quantity of spirit and let a lad brush the casing over, *after* the

cables are in. The casing itself must be made to take up as much shellac as its pores will hold, and have at least one glazing coating over all *before* it is fixed.

Shellac varnish is made by dissolving shellac in methylated spirit, the office of the latter being merely to convey the particles of shellac in a finely divided state into the pores of the wood. After it has done that, it may evaporate. If only a small quantity of shellac is dissolved in the spirit only a small quantity finds its way into the wood, and consequently, when the spirit has evaporated, it is doubtful if the wood is much the better for it. By making a varnish saturated with shellac, and either steeping the wood in it, or else drying and painting it with successive coats, the wood casing itself becomes almost impervious to moisture, and a fairly good insulator, affording not only the mechanical protection required, but also additional insulation. Stockholm tar or paint, laid on in several coats and allowed to dry, also answers fairly well.

Another point that requires careful attention, in order that the use of wood may be in no sense a danger, is the covering of joints. It is, unfortunately, absolutely necessary to break the insulating covering where branch wires have to be joined in—say to feed lamps—just as it is necessary to break a steam or gas pipe in some way to attach a branch. We cannot get a current of sufficient strength out unless we get right to the conductor which is carrying the main current. Much may be done, however, by care and practice, to minimise the risk of jointing. If we can re-make the containing insulating envelope just as it was before, there will be no danger of any leakage of current, unless oil

or water has been allowed to get inside the covering. With guttapercha covered wires this may be accomplished by covering the joint with guttapercha, of exactly the same composition as the coating of the wire, and carefully welding the two together under the influence of heat. A certain amount of practice is necessary to accomplish this, as warm guttapercha is not easily handled; and further, the insulating covering of so-called guttapercha covered wires is often not pure guttapercha, but a compound containing that substance; and it will often happen that, after the most careful manipulation, there is a distinctly marked crack between the two substances, that covering the joint and the coating of the wire, through which the moisture enters. This danger may be minimised where it is unavoidable, by carrying the covering of the joint well back over the insulating covering of the wire. With indiarubber covering, the use of indiarubber strip, carefully applied with solution of indiarubber, will make a better weld than is usually obtainable with guttapercha. The plan adopted with indiarubber covered wires is to remove the outer tape or braiding, cover the wire joint with sheet indiarubber, laid on under tension, carrying the lapping back a little over the covering of the wire, saturating the whole with rubber solution and covering with ordinary tape soaked in rubber. This is the method adopted for jointing the cables of submarine mines. An important point, however, should not be overlooked, viz., the formation of the wire joint itself. This should be so made that no artificial resistance is interposed between the two metallic surfaces, such as dirt; and that there shall be no possibility of the joint itself working loose

under the strain of vibration, pitching, etc., and allowing a spark to pass. As will be explained later, when you have a spark passing between two surfaces, you have intense heat developed, quite out of proportion to the size of the metals between which the spark is passing, or even of the spark itself; with the result that no end of trouble follows. In the presence of a spark moisture becomes steam, and bursts all sorts of envelopes that it would have been sup-

Fig. 30.—Joint in Solid Wire, ends scarfed, ready for binding.

posed could not have been moved. It is this enormous expansive power, following upon the passage of an electric spark, that causes those mysterious troubles with lightning. Huge coping stones are caused to jump out of places they have occupied for centuries, because there has suddenly been created a path for a lightning flash through them, and so on. Therefore, before all things,

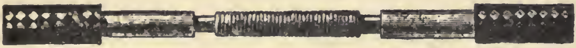


Fig. 31.—Finished Metallic Joint in Solid Wire.

see that your metallic joint is mechanically as perfect as if it had to bear a heavy pulling strain. Solder it where possible, but, if you do, be very careful to leave no spirits free, or you will have left another legacy of trouble. If you can, solder with resin; but as few workmen have the patience to do this, kill your spirits thoroughly, and burn or wipe off every vestige of acid or moisture before covering the joint up. Figs. 30

and 31 show how joints should be made. Fig. 30 shows the ends of a pair of stout wires with their ends scarfed ready for binding together. The object of scarfing them is, of course, to make a neater finished joint, but great care must be taken not to weaken the wire too much in the process; and, in particular, not to nick it with the file or knife that is used in trimming the copper down, as the wire will be sure to break at the place where it is nicked later on.

For small wires it is sufficient to place the two ends side by side. In either case, whether the wires are scarfed or not, the ends, when married, are neatly bound with a piece of fine copper wire, and very carefully soldered. Be very careful to leave no ends of wire pointing up through the covering, as any of these will invariably break down the insulating covering before very long. In removing the covering from the end of the wire also, preparatory to jointing, be very careful not to cut or nick the wire itself, as may easily be done, just where the covering ceases. Bear in mind, too, that if you leave any moisture or spirits inside the covering of your joint, you have left a small galvanic battery, which, with the assistance of the lighting current, will part the cable at the joint, and you may have considerable difficulty in finding the place where the break occurs. Messrs. Henley's Telegraph Company have kindly allowed the writer to make use of the following instructions for jointing stranded cables.

First strip the insulation back for a few inches to allow sufficient space for soldering, without injury to the indiarubber. Then solder. In stranded wires it is

advisable to wrap the strands with a tinned copper wire, thus—

Fig. 32.

Avoid all sharp points, and do not allow ends of wires to stick out, or they may pierce the pure india-rubber.

After soldering (without acid) cut back the insulation of the cable or wire in tapering form, thus—

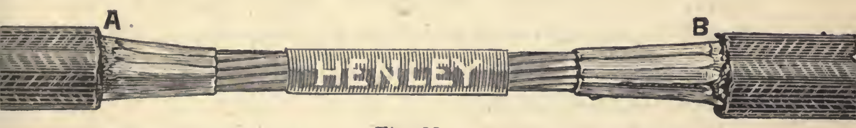


Fig. 33.

Rub a very little rubber solution on the wire itself and the tapered ends of the original rubber insulation, then wrap with pure rubber strip from one end to the other, and back again, so as to give at least three layers of pure rubber.

Care should be taken to start at A, and work as far as B, but not over the outer braiding. In working up on to the tapered ends of the insulation of the cable or wire, you get rubber next to rubber, and the solution has a tendency to amalgamate the two.

Be careful not to use too much solution (more than above mentioned is liable to work injury), and in lapping the pure rubber, a continuous and heavy strain should be kept up, causing a small film of solution to ooze through between the lappings.

This is quite sufficient to render the three layers of strip adhesive, and ultimately homogeneous.

N.B.—The strip should be thoroughly overlapped, thus—

Fig. 34.

After the thorough lapping with the pure rubber as above, two or more lappings of double proofed tape should be wound on in a similar manner, and as tightly as possible. The last end may be fastened by a slight application of solution.

For T joints, where small wires are jointed to larger ones, the same method applies, except that no marriage is required, the smaller wire being merely wrapped round the larger one.

Four important Rules.—Avoid acid in soldering—use resin where necessary; do not use too much solution; lap the pure rubber strip as tightly as possible; cleanliness is of the utmost importance. (Where possible the work should be divided so that one operator does the cutting away, another the soldering, another the pure rubber lapping, and so forth. It is certain that a man with his hands smeared with solution cannot make a clean joint.)

Never secure your cables or branch wires with staples, as they will work their way through the covering of the cable to a certainty; and the least trouble you will then

have will be one of those small galvanic batteries formed by the copper wire, the iron staple, and the moisture which is sure to be present, and which will gradually eat your copper wire in two, the lighting current itself helping.

In the early days, before electric lighting, we used to be very chary of using staples whenever we had any reason to expect damp; but in those days a parted wire was the only trouble we feared. With electric light cables the danger is much greater. It is the same that has been already pointed out in connection with the use of the skin of the ship as a return, viz., that a conductive passage may be formed from one cable to another, giving rise to sparking and to dangerous heating. Where the two cables are under one staple, the passage is by way of the staple, as soon as the latter has worked through both coverings. Where the two are stapled separately the passage will be by way of the staples and the intervening wood, when the staples have worked through the insulations of the cables, and the wood between has lost its insulating properties, either from the presence of moisture, the action of the current, or other causes. Therefore, if you are unavoidably obliged to staple a wire or cable temporarily, cover the wire itself with cloth or rubber, outside its regular covering, so that the staple may have something more than the indiarubber coating of the wire to work through, and staple the two cables as far apart as possible, so that the conductive passage, when it is formed, will have as high a resistance as can be arranged. This rule, so arranging matters that any leakage current which may be present has a good deal to do, and is therefore much

weakened, is applicable in all cases of electrical work; and its adoption will be found to increase the life of the cables. Another point that is worth noting is that the joints in the two cables, to connect to branch cables or to a lamp, should never be made opposite each other. Make them as far apart as you can, so that, should the joints have been imperfectly made, there may be no chance of the two metallic surfaces coming in contact or within sparking distance.

A case that came within the writer's experience, though properly belonging to the section dealing with the location of faults, will be given here, as he is on the subject. It led to serious consequences. A private house in the neighbourhood of a colliery was supplied with electric light from a dynamo running at the latter. Three of the lamps were attached to a gas chandelier in the drawing-room, and the wires leading to them passed through an iron plate which supported the chandelier. In the flooring of the bedroom overhead, the wires leading to these lamps and others—wires between which an electric tension of 100 volts existed—were jumbled together in a tangle between the joists on their way to the switchboard in the hall. It appeared that what is known as an earth connection was formed at the dynamo —that is to say, one pole of the dynamo, or one cable, became connected to the gas service. It so happened that one of the small wires in the tangle under the floorboards was in connection with the other side of the dynamo through the distributing switch before referred to. A portion of this jumble of wires laid on the iron plate which was over the chandelier, and some of them were jointed there to the flexible cord leading to the

lamps below. Parts of the wires laid on the sharp edge of the iron plate. Further, the wires were very thinly covered with guttapercha. One winter morning, while the master of the house was dressing, the housemaid went to clean the dining-room, and to light her, while she was doing so, plugged in one lamp at the switch. Hardly had she done this than the lamp went out, and there was a blaze in the neighbourhood of the switch, which was fortunately promptly smothered. The heat, however, was so intense that it melted the bell wire which ran close to the ceiling. Subsequent investigation showed that continual walking on the loose board over the chandelier had gradually worn the insulation of one of the wires through, and possibly the master of the house, who was a heavy man, standing on it that morning, had made the final connection, previous to the housemaid plugging in the lamp. This fault was a troublesome one to find, as the fire caused by the current partially destroyed the causes which led up to it, and one was rather liable to be led away from the main issue by the fact of the bell wire having been fused, as this is what would have happened if that wire had itself helped to produce the trouble.

CHAPTER IV.

ELECTRIC LAMPS AND THEIR FITTINGS.

NEXT we come to the lamps that are used to convert the current into heat and light. There are two methods by which this may be accomplished, viz. by the arc,—a spark passing between two carbon points, and by the direct heating effect of the current when passing through a thin filament, as it is termed, or thread of carbon. The result in each case is due to the same cause, viz. the heat generated by the current when it is forced through any body in opposition to a high resistance; but where the resistance takes the form of a total break in the circuit, only bridged over by a spark, the heating effect is far more intense—at least ten times—for the same power, and for the same current strength, than where the current is opposed only by a conductor without break. It is for this reason—as will be explained later on—that sparking is to be so carefully avoided in switches and other accessories. On board ship the arc lamp is only suitable for search lights and for the head lights used in passing through the Suez Canal, and only there because such an intense beam can be obtained at comparatively small cost, and because the whole source of the light being concentrated within the small space occupied by the arc itself it can readily be focussed in

a lens and reflector, so that the beam in any direction is very much magnified.

The incandescent lamp, in which the light is given out by a glowing hair-like filament of carbon, is suitable for all purposes, except where the light must be focussed. It is now made in sizes to give from 5 candle-power up to 2000 candle-power. The *rationale* of the incandescent lamp is as follows:—It will be remembered that the property of offering resistance to the passage of the current has been mentioned, and that it was stated that some bodies opposed a higher resistance to the passage of a current than other bodies of the same dimensions. If, for instance, equal lengths of copper and iron wire of the same gauge be connected to the terminals of a dynamo furnishing a given EMF, it will be found that about six times as much current passes through the copper wire as through the iron. If a platinum wire of similar dimensions were connected to the same terminals, a still smaller current would pass, and even less through a carbon wire, if we could make one. If, on the other hand, we take pieces of iron wire, copper wire, platinum wire, and carbon of the same section, if we can get them, and connect these together, and to the dynamo terminals, in such a manner that the current passes through each wire in succession, the current strength being the same in all, we shall find that when the carbon becomes hot all the rest will remain cold; that if we increase the current strength until the platinum becomes hot the carbon will be white and on the point of fusion, while the copper will still be cold, and if we increase the strength of the current until the copper becomes white hot the others will fuse.

The reason of this is to be found in the law which has been given for the heating effect produced by the current, viz. $H = C^2Rt$. Where H is the heat generated in a conductor in a given time, C is the current strength in ampères, R the resistance of the conductor in ohms, and t the time in seconds. For a current of a given strength, therefore, passing for a given time, the heat generated is directly in proportion to the resistance of the body through which the current is passing. It is for this reason that copper is chosen for cables to distribute the current, and for the wires of the dynamo which generates it, while carbon is chosen for the lamp which consumes the current. In the first case we require as little heat as possible, because it tends to destroy the insulating covering of our wires and wastes energy. In the latter case we require as much as we can get, because we have no insulating covering to destroy, and we want the heat, or as much of it as possible, to be converted into light.

Another point should also be mentioned here, as it has a considerable bearing upon the effects that certain current strengths, and certain electro-motive forces have upon the conductors to which they are applied, viz. the effect which the passage of the current itself has upon the body through which it passes, by generating heat in that body. With metals the effect is to increase the resistance offered by the body, so that, if a copper wire of a given length and gauge be connected to the terminals of a dynamo, the tendency of the current is to increase the resistance offered by the wire, so that less current passes than the dimensions of the wire and the EMF applied would have argued. For this reason, the

resistances of wires that are to work at a higher temperature than the standard, 60° F., such as those on the bobbins of dynamos, are measured at their working temperature, and in calculating the size of wire for a dynamo an allowance is made on the score of its increased resistance, due to increased temperature when at work. This phenomena also leads to some curious results in other directions. In testing a dynamo, for instance, without lamps, to see what work it will do, it would be a convenient method of providing a conductor for the passage of the current outside the dynamo, to stretch a small iron wire in air and connect its two ends to the dynamo terminals. But it is found that, after a certain current strength is reached, no more will pass even if the wire be shortened in length, as the resistance of the wire rises more rapidly than the current strength passing, owing to the rapid increase of the heat generated; for this reason, if a wire or metal strip is used for testing the output of a dynamo in this manner, it must be so proportioned that the current passing generates very little heat in it. Another case where this property of the increase of resistance due to increased temperature is sometimes troublesome, is with the fine wire instruments used for measuring the pressure or voltage. With nearly all these instruments, if they are connected permanently to the source of current, say to the dynamo terminals, though the current passing in the coils of the instrument is so small as to be of practically no value, and has no effect upon the work done by the dynamo, and that no heating can be detected in the coils of the instrument, yet the resistance of the wire of these coils rises, with the result that a smaller current passes, lowering the

readings of the instrument. It is no uncommon thing to have a test put all wrong from this cause. On the other hand, as will be explained when dealing with measuring instruments, this very quality, the rise of temperature caused by the conversion of the electric current into heat, has been made the means of measuring the pressure in volts of the current itself.

For all incandescent lamps at present in use carbon is the material of which the conductor is formed. In the smaller lamps the filaments are prepared from some vegetable substance, such as cotton thread or a strip of bamboo, by treating them with sulphuric acid and baking in a closed crucible. As the result of this treatment a sort of skeleton of the original material is produced, very fragile. It is then placed in its glass globe in which it is to burn when in use. The latter is filled with ordinary coal gas, and the skeleton of the filament itself is built up by minute increments of carbon deposited in it from the molecules of the gas itself, the filament being maintained at a certain temperature during the process. The ends of the filament are connected to small platinum wires passing through the glass globe and sealed into it, platinum being the only metal whose rate of expansion under the influence of heat, bears such a proportion to the rate of expansion of glass, as to allow of the joint remaining air-tight when the wire and glass become cold. The platinum wires are either formed into loops on the outside, or are connected to brass plates held in a brass collar surrounding the base of the lamp. The top of the globe is drawn down to a fine tube, exhausted under the air-pump, and sealed off. Great care is necessary in exhausting the globe from air, in sealing off,

in connecting to the platinum wires, and in building up the filament from the hydrocarbon gas. If any appreciable quantity of air is left in the globe, or there is a flaw in the glass, or in the sealing, by which air can penetrate to the filament, the latter will only last a few minutes when the current is allowed to pass through it, as the carbon will immediately oxidise and burn out. If, also, there be any weak point in the filament, such as would be produced by a kink, or by two portions of a curl of those made in that form hanging together, the filament will usually part at that point after a very short time of burning. The filament, when finished and sent out ready for use, has a metallic look, not unlike some qualities of steel in certain states, or the grey metallic look of some qualities of coke. The globe itself is also clear. If on examination a black spot, the colour of soot, appears on the filament before being used, it will probably break at that point after burning a short time. From the moment the lamp is used for illuminating purposes the carbon filament begins to disintegrate, small particles of the carbon depositing on the glass, which soon assumes a blackened appearance. This has the effect of doubly reducing the light given by the lamp, the cloud upon the glass obstructing the rays from the filament, and the deposit of carbon taken from its mass reducing its sectional area, and thereby increasing its resistance. If the current strength was maintained constant, though the mass of the filament decreased, this would have the effect of increasing the light given by the filament, in accordance with the terms of the formula $H = C^2Rt$, as already explained, the light given by the lamp being proportional to the heat generated in the

filament. But the resistance of the filament increasing from the reduction of its mass, owing to the deposit, less current passes through it, and, therefore, less light is given out; again, in accordance with the formula quoted above, because, as will be seen, while the heat generated is simply proportional to the resistance of the filament, it is proportional to the *square* of the current passing. Take a lamp, for instance, which gives 16 candle-power when first made, and which is made for a 100-volt circuit. This lamp will take ·6 ampère when new, and its resistance hot will be about 166 ohms. Suppose that its resistance increases to 200 ohms, by Ohm's law, we have $C = \frac{E}{R} = \frac{100}{200} = \cdot 5$ ampère, and the light given by the lamp, now that its resistance is increased, will be to the light given by it before as $\cdot 5^2 \times 200 : \cdot 6^2 \times 166$, or as 50 : 59·76. Approximately the light has decreased about one-sixth, in addition to that lost by the clouding of the lamp globe. Where lamps can be used that are not giving much light this property enables a lamp to have a very long life, as it is evident that the strain upon the lamp decreases as its resistance increases. In some mines, with which the writer is connected, special lamps of 16 candle-power have in this way attained a life of as many as 26,000 hours, and a life of 7000 hours has been quite common. The very long-lived lamps referred to have been exceptionally good lamps in the first instance, and have been placed in positions where the decrease of light was not of much consequence. Two points should be mentioned here in connection with the incandescent lamp. It will be remembered that the method of current supply adopted on board ship is

always that known as the parallel or constant EMF system. Two mains, or one main and the skin of the ship, have a certain EMF between them whenever the dynamo is running and connections are perfect; and the current is passed through the lamp by connecting it to these mains, bridging it across them. Therefore, the EMF at its terminals being constant, it follows from Ohm's law that if from any cause the resistance rises in that branch of which any particular lamp is a part, less current must pass through the lamp, and therefore less light would be given out by it. This would not be the case where what is known as the series system is adopted. Such a system is totally unsuited for ship lighting, but it has been used, to a small extent, in town lighting—notably at Taunton, in Somerset, and it was used in a modified form in the early days of the incandescent lamp, before the advent of the compound wound or constant EMF dynamo. At Taunton, incandescent lamps of 32 candle-power were connected in the arc circuit, and were made to take the same current as the arcs were using, but only a low EMF, the filament being comparatively short and stout. This plan was adopted in Taunton because only a few incandescent lamps were required for special purposes, the principal lighting being done by means of arc lamps, and it would not therefore have paid to have laid down plant and supply wires specially for them. A special arrangement was also added in each case to provide a path for the current in case the filament of one of the lamps broke. At Taunton also, and at a great many other places, what is known as the parallel series system was adopted when the old series-wound dynamo was the only one available.

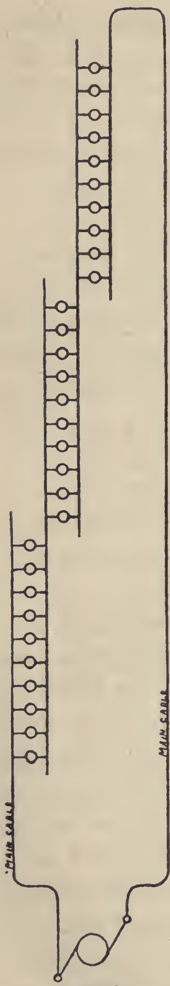


Fig. 35.—Showing arrangement of Incandescent Lamps in Series-Parallel.

In this system, which is shown in Fig. 35, the current which passes through the arc lamps is divided between as many incandescent lamps as it will supply. Thus, a 10-ampère current would be divided between the ten lamps, each taking 1 ampère, or between twenty lamps, each taking ·5 ampère, and, after passing through one set of ten or twenty, might be divided between another set of ten or twenty, and so on. It was not necessary that arc lamps should be worked from the same dynamo; it might be used only to furnish incandescent in two, three, four, or more parallels,—the parallels themselves being connected in series with the dynamo. With this arrangement the working conditions tended to make individual lamps give more than their normal light. Thus, if from any cause, say, simply difference in manufacture, the resistance of one lamp was lower than that of the others, it would allow more current to pass through, and would give more light than the rest. If, too, any one lamp happened to be structurally weaker than the rest, and not able to stand the same current, possibly giving way after a few days' burning, the total current divided itself through the rest in the inverse ratio of their resistances, so that all had a share of the current that had

passed through the faulty lamp, and each gave more light. If, now, a second lamp gave way under the increased strain, its current was divided between the rest, and so it went on till it was by no means unusual for a whole parallel of ten, fifteen, or twenty lamps to be destroyed in this way. The writer has thought it advisable to mention this, as, though the system is now quite out of date, there may be some installations still in existence.

The other point that should be mentioned is the peculiar behaviour of carbon with reference to its resistance under the influence of heat. The electrical resistance of carbon falls instead of rising as its temperature increases. In fact, with some incandescent lamps, the resistance of the filament when hot is just half that when cold. This phenomenon leads to another curious result. When lamps are working from any dynamo, if the speed of the dynamo increases, or the EMF at the terminals of the lamp increases, from that or any other cause, the increased voltage not only forces a larger current through the lamp in opposition to the present resistance of the filament, but it decreases the resistance of the filament itself by reason of the increased heat generated by the increased current strength. As the heat generated varies as the square of the current strength, the light given goes up or down very rapidly with a varying EMF. With the old series wound dynamo the effect was considerably increased by the behaviour of the dynamo itself, unless its field-magnets were magnetised to about what used to be called saturation limit. An increase of speed gave rise to an increase of EMF at the terminals of the dynamo; that to increased current through the lamps; that, again,

to decreased resistance of the lamp filaments and a further increase of current strength. The increase of current strength, due both to the increased speed and the decreased resistance of the lamps, gave a further increase of EMF, due to the increase of magnetism in the field-magnets, so that a comparatively trifling increase of speed might seriously strain the lamp filaments.

Figs. 36 to 39 show the different forms in which the smaller incandescent lamps are made. Fig. 36 shows Mr. Swan's earliest type; Fig. 39, Mr. Edison's first type. In Fig. 36 the ends of the platinum wires, which it will be remembered form continuations of the filament, on the outside of the globe, are formed into two loops, which are made to engage with a pair of hooks that are attached to some of the forms of holders that will be described. The objection to this form of lamp is—if there is much vibration, as there always is in some parts of a large steamship, the hooks of the holder, or one of them, may be temporarily loosened from their hold on the platinum loops; and if this should happen, a spark would pass between the two, which might melt either the loop or the hook, or both, and the lamp might fall to the ground and be broken. Many lamps have been destroyed from this cause, and it used to be a frequent source of trouble before the advent of the capped lamps shown in Figs. 37 to 39.

A lamp-holder was invented some years since which partially provided for this trouble. The platinum loops were held between small pairs of contact pieces, forced together by screws, and the globe was supported by a loop of brass wire, an eye in which engaged the glass

point in the bulb. Unfortunately the supporting loop

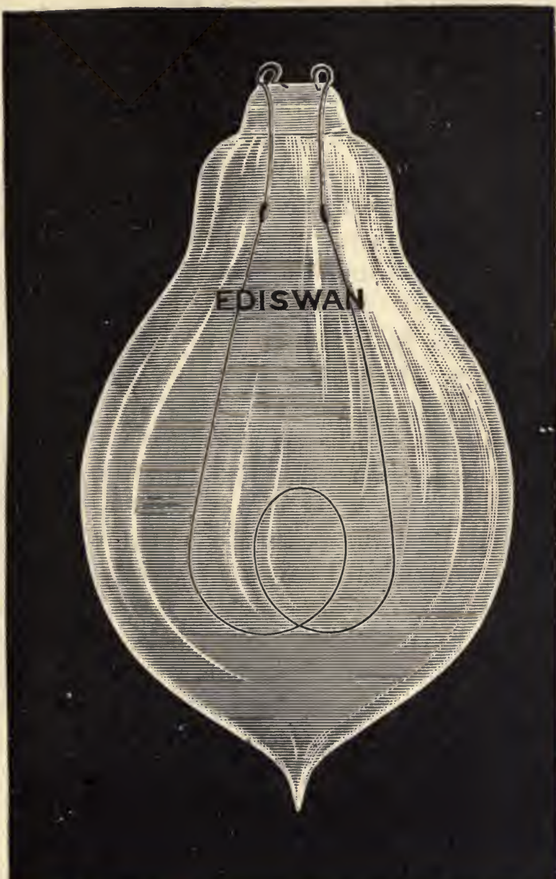


Fig. 36.—Showing Glow Lamp with Loop Terminals.

cast a shadow, and the holder was troublesome to fix, so it fell into disuse. It is even now not uncommon,

where looped lamps are in use, to see a lamp hanging from its branch wires, the ends of the latter having been formed into hooks for the purpose. As it is necessary that a certain length of the wire shall be bared in order to engage with the platinum loop, it will readily be understood that, unless great care is used, it may easily happen that the wires will be left so that a little vibration, or a little pressure, will bring them into contact with each other, causing trouble not only at that lamp, but possibly a fire also.

It may as well be mentioned here that the case mentioned—that of the naked branch wires coming into contact—forms one of the most likely causes of fire from electric lighting currents. It will be remembered that the heating effect in any conductor varies in accordance with the formula: $H = C^2Rt$, where H is the heat developed in time, t, C is the current strength in ampères, and R is the resistance of the conductor. It will also be remembered that the current passing in any conductor varies directly as the EMF present, and inversely as its resistance. Now, between the branch wires of the electric light service, where they are connected to the terminals of the lamp, there exists nearly the full EMF developed by the dynamo; in fact, the full voltage, less the charge made upon it for the working current passing through the main and branch conductors. If the resistance offered by the filament of the lamp and its platinum terminal is removed, the only resistance offered to the passage of the current will be the short length of wire leading to the lamp, and that of the contact between the two wires. As the sum of these two is small where good metallic

contact is formed, a very powerful current will pass through the main cables and branch wires, heating the latter probably to a red or white heat, and setting fire to any inflammable substance in its neighbourhood. To see the enormous increase in the current strength caused by the short circuiting of a lamp, as it is termed, take the case already mentioned, viz. a service of 100 volts, and a lamp having a resistance, when its filament is hot, of 166 ohms. Suppose that one volt has been expended in reaching the lamp, through the resistance of the main and branch wires, leaving the voltage at the terminals of the lamp 99 volts. Now, let the resistance be suddenly reduced to ·25 ohms, as may easily be done by the supply wires coming into contact, then, by Ohm's law you have

$$C, = \frac{E}{R} = \frac{99}{\cdot 25} = 396 \text{ ampères}$$

passing through a wire which was intended to deliver a current not exceeding 1 ampère.

Applying the formula $H = C^2Rt$, we have the heating effect of the current in any time t, 396^2, or nearly 160,000 times the heat of the maximum current it was intended to allow. It should be mentioned here, though, that occasionally the contact of supply wires does not have this effect, owing to their being covered with dirt or oxide, and loosely touching each other. Dirt and loose contacts have a very high resistance—so high, in fact, as often to prevent the working of electrical apparatus, by interposing a large resistance in the path of the current that should have worked it, and thereby reducing the strength below the figure at which

the apparatus would work. Dirty contacts between the

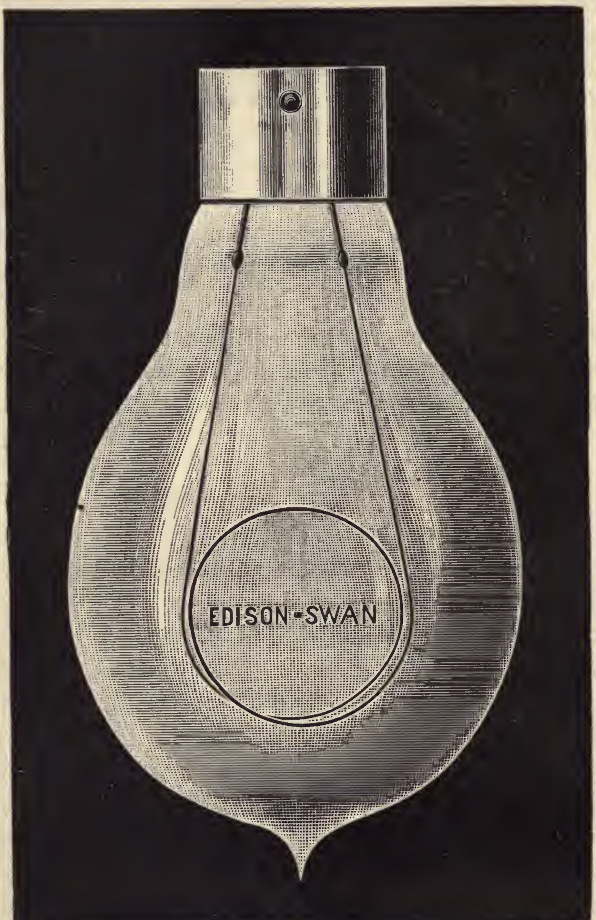


Fig. 37.—Showing Glow Lamp with Brass Collar.

parts of switches, or between the terminals of the lamp

and its holder, often dim the light given by the lamps they support or control. Dirty and imperfect contacts also usually give rise to sparking, which again leads to fusion of the wires or metallic parts. The writer has mentioned this in order that it may not be imagined, where one of these exceptional cases does happen, that bared wires can be used with impunity.

In Fig. 37 is shown what is known as a bottom-capped lamp. In this lamp the platinum wires are connected to two brass plates, shown on the bottom of the lamps. The base of the lamp is enclosed in a collar of brass or vitreous substance called vitrite, the space between the glass, the collar, and the plates being filled in with plaster of Paris. Two pins, one on either side, serve as guides for the lamps in the bayonet socket holders they are used with.

The bottom-capped lamp is a decided improvement upon the bottom-looped lamps. The lamp is easily and quickly fixed in its holder, and the old lamp is even more easily removed, a turn to the right or the left being all that is required, while with looped lamps it was often a very troublesome matter to engage both hooks in their respective loops.

The capped lamps that were first made, however, had a fault which is even now not always absent. The plaster of Paris which is used for the setting of the collar and plates absorbs moisture if in a damp place, and it then becomes soft, with the result that the lamp if suspended with the bulb down, as is most frequently the case, is released and falls to the ground, usually breaking in pieces. For this reason capped lamps have not come into such general favour as would have been

expected, especially for outdoor work and damp

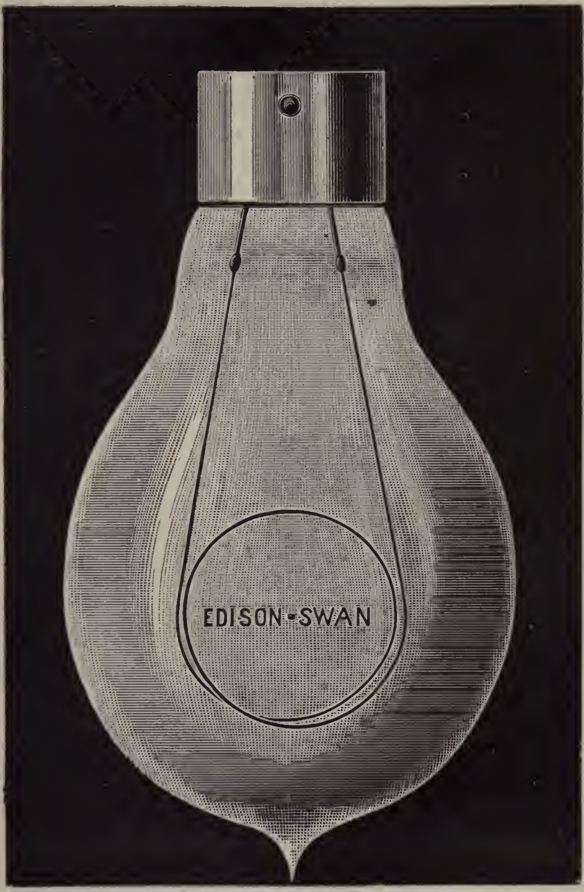


Fig. 38.—Incandescent Lamp, with Central Plate and Collar Terminals.

situations. Much may be done, however, to prevent the moisture getting into the plaster of Paris. Varnish-

ing the joints between the brass ferrule of the lamp-holder and the glass on one side and the base of the holder on the other, will help to prevent moisture from penetrating very much. Indiarubber rings slipped over the joints will do the same. A capped lamp with a bone disc at its base has lately been introduced, but it is found that the bone absorbs moisture also and swells. Fig. 38 shows a capped lamp, with what is called a central collar terminal. One of its platinum wires is connected to the brass collar itself, and the other to a circular brass plate placed in the centre of the collar as shown. The base of the lamp is filled in with plaster of Paris as before. This lamp is intended for those cases where the skin of the ship is used as a return. Holders are made with central contacts to engage the circular plate, as will be described. Fig. 39 shows another central contact lamp, but in a different form. The collar in this case is made into a coarse-pitched screw, the thread being made of insulating material, overlaid with a thin coating of a conducting substance, such as foil. One end of the filament is connected to this metallic screw, and the other to the projecting contact piece at the bottom, which is also covered with foil. This lamp fits into a socket known as the "Acorn" pattern, from its form. As will be described later on, the lamp screws into the holder until its contact piece at the base bears against a spring placed in the bottom of the holder for the purpose. The Acorn socket and its lamp were rather favourites with the Electric Light Supply Companies in their early days.

Incandescent, or glow lamps, are now made of all candle-powers, from the very small lamps, used for breast pins and for ladies' hair, up to lamps of 2000

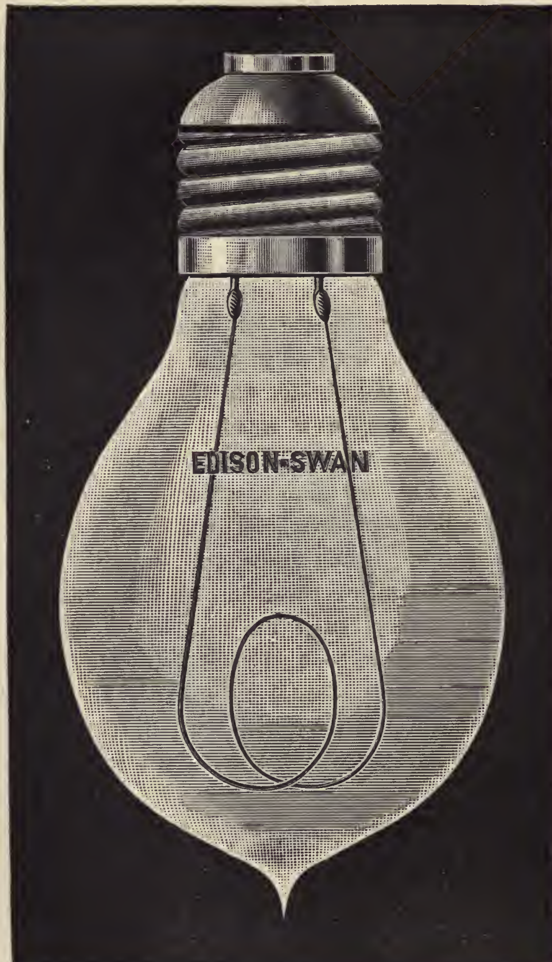


Fig. 39.—Showing Edison Lamp with Acorn Terminal.

candle-power, though, so far as the author's experience goes, about 800 candle-power is the largest serviceable lamp at present. They are also made for any voltage from 15 up to 160 volts, with the exception of the small lamps, 5 candle-power and under, which are only made for very low voltages.

The difference in the candle-powers of the various lamps, and in the voltage with which they are to be used, is effected by varying the size and length of the carbon filaments. Thus the filament for a 16 candle-power lamp, to work on a 60-volt circuit, is thicker and larger in cross section than that of a 16 candle-power lamp to work on a 100-volt circuit.

The filament of a 50 candle-power lamp of any voltage is thicker and larger than that of a 16 candle-power lamp for the same voltage; while the filament of a 100 candle-power lamp is thicker and larger than that of a 50 candle-power lamp, and so on.

Some of the lamps of higher candle-power are made with two or more filaments; and some of the lamps made for higher voltages, in which the filament is necessarily long and thin, are also made with two filaments.

One of the difficulties with the lamps of higher candle-power has been the great amount of heat generated, and the great strains brought upon the glass, if the latter be suddenly cooled, as by a drop of water falling on it in the open.

For lamps of 100 candle-power and upwards, and sometimes for lamps of 50 candle-power, the cap that was shown in Figs. 37 and 38 has been obliged to be abandoned, on account of the great heat generated. In place of the cap, therefore, with its collars and plates,

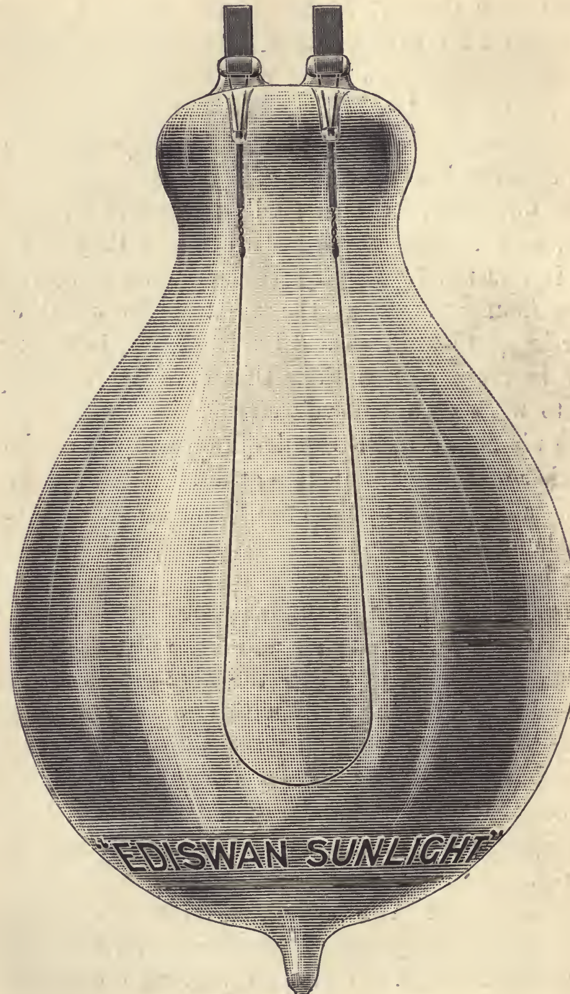


Fig. 40.

lugs or strips of copper are used, as shown in Fig. 40, which clip between the clamps provided for them in the lamp-holders shown in Fig. 41.

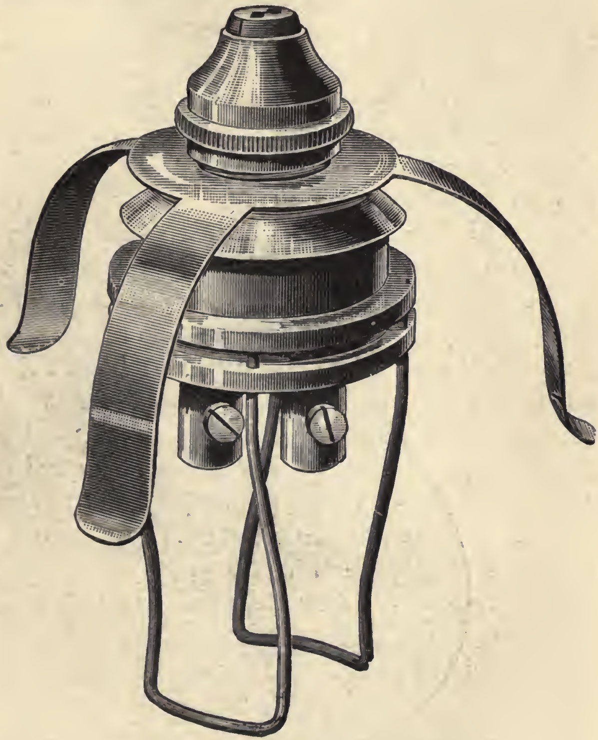


Fig. 41.—Showing Lug Lamp-Holder.

In Figs. 42 to 45 are shown some forms of incandescent lamps made by the Edison-Swan Co.

Fig. 42 shows a lamp which has been designed specially for placing in the focus of a lens or mirror, where that is required. It will be observed that the filament

in this lamp is made into a very short coil, so that the body of light occupies only a small space, just as it does in the arc lamp, and is not spread over a long loop, as

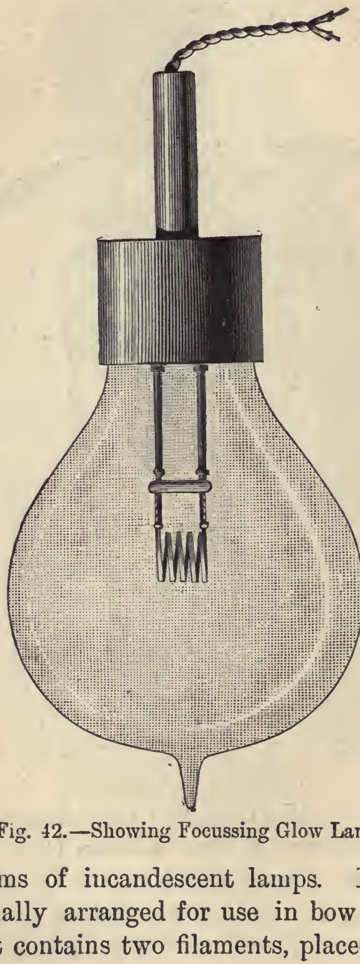


Fig. 42.—Showing Focussing Glow Lamp.

in other forms of incandescent lamps. Fig. 43 shows a lamp specially arranged for use in bow and masthead lanterns. It contains two filaments, placed parallel with

each other, each taking its own current and giving its

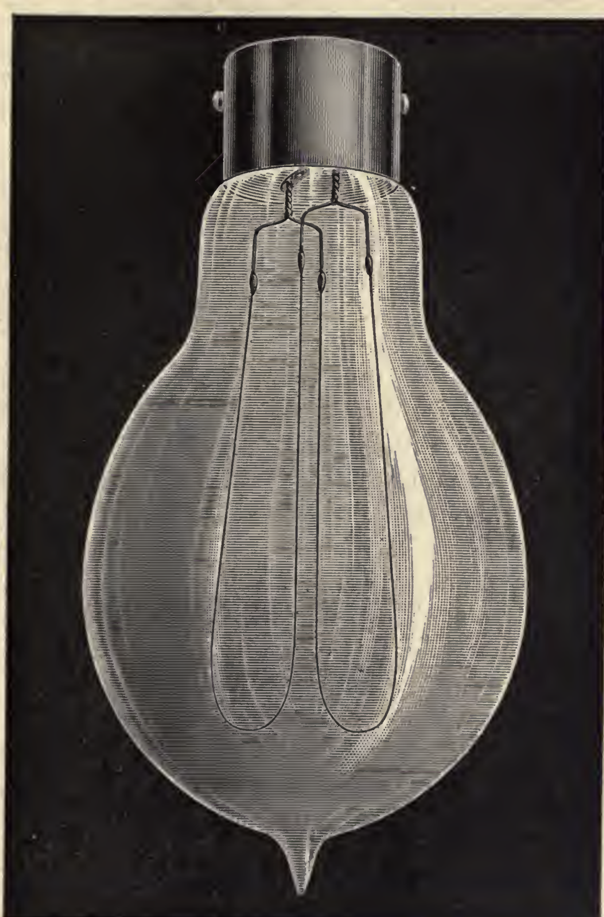


Fig. 43.—New Edison-Swan Lamp for Bow and Masthead Lights.

own light, the object of the two being that in case one filament goes, the lamp merely gives less light, but does

not go out. Experience must decide how far this is a real advantage, or whether greater safety would not be attained by using one stronger filament giving a light equal to that given by the two filaments. The writer would incline to favour the larger filament, subject, of course, to actual experience of a new thing. In his view, it is better, in the case of bow and masthead lights, to rely on one strong filament, the lamp being carefully examined every day, and replaced immediately it shows any sign of weakness at any one point, or when its filament has been reduced below a certain section. It is very probable that the intense heat generated by the spark which passes usually at the moment when a filament fails would destroy the other filament that is to be relied on to maintain the light. In addition to this, the bombardment of minute particles of carbon which takes place from each filament when burning upon the glass, would also take place upon the other filament, and it is by no means certain how this would affect the life of the lamp as a whole. Fig. 44 shows a lamp made for ornamental purposes, that would look very well indeed in the saloon. In this lamp the ordinary glass bulb is replaced by one of cut glass or crystal, the effect of the light shining from each portion of a prism being very soft and pleasant to the eyes. There are a number of this class of fittings, that have been named by their inventor "dioptric," presumably from a certain resemblance they bear to the ordinary dioptric lens. They are very effective in drawing-rooms. Fig. 45 shows a lamp with two filaments in series, for high voltages.

Next to the lamps come the lamp-holders. At present these are made separate, as it may sometimes be

necessary to change the lamp without changing the

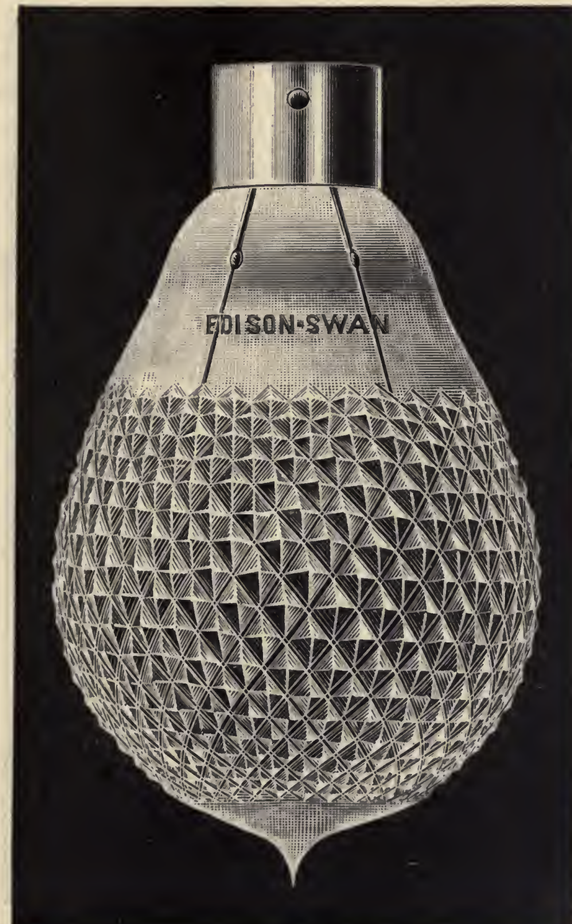


Fig. 44.—Ornamental Glow Lamp.

holder, and *vice versâ*. In the writer's opinion, however,

it would be a great improvement if the lamp and holder

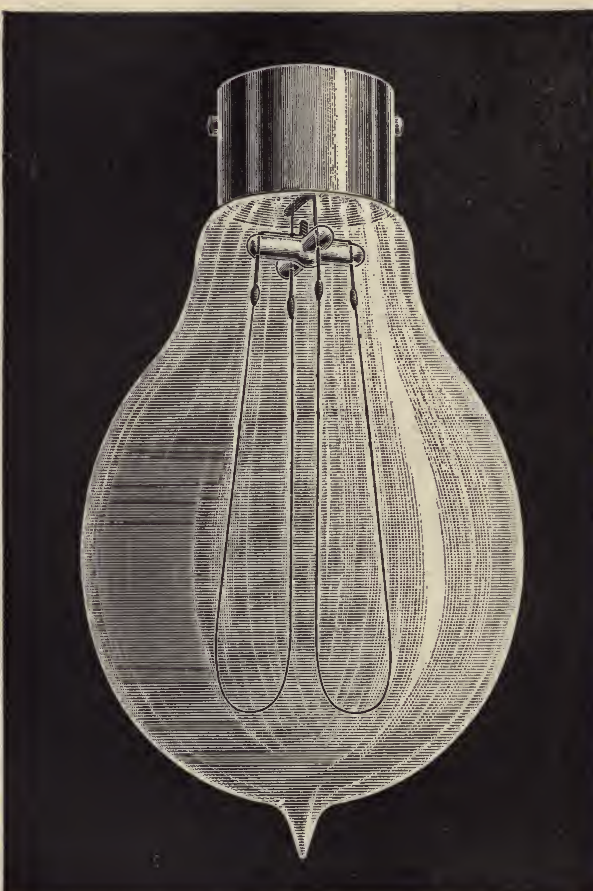


Fig. 45.

were made in one, supposing that it could be done satisfactorily, as the connections between the two often give

considerable trouble. The office of the lamp-holder is twofold. It is required to support the lamp, and to provide a means of conveniently and quickly connecting it to the supply wires. With the advance in the manufacture of porcelain, the tendency has been to make all lamp-holders of that material entirely; the reason being that, where wood is used, even very dry, hard material, the intense heat of the spark or arc, which a faulty contact may set up, practically destroys the holder, the wood in the neighbourhood of where the spark has been passing being completely charred. In the early days of electric lighting, however, wood was good enough, and it was better than porcelain, because it could be made into any form that was required. The earliest lamp-holder was one brought out by Mr. Swan, in which a large spiral spring held the base of the lamp, and two hooks engaged with the loops. This form, which is shown in Fig. 46, has nearly gone out of use. It was found very troublesome to hook the loops on against the pressure of the spiral, and particularly, as was often required, in the dark. In this lamp-holder the terminals for the supply wires to connect to were outside.

Fig. 46. — Showing original Swan Lamp-Holder, for Looped Lamps.

The method of attaching the wires forms one of the weak points of the suspension holder, the lamp being entirely dependent upon the screw terminals being fast down, and the wires well under the screws and all intact.

It is fair to say, though, that not many cases of breakage have occurred from these connections giving way, so far as the writer's experience goes, but it is as well to be warned of the possibility.

In many cases a knot is tied in the cord above the holder, which then helps to support the lamp and holder; but this practice is very much to be condemned, as the

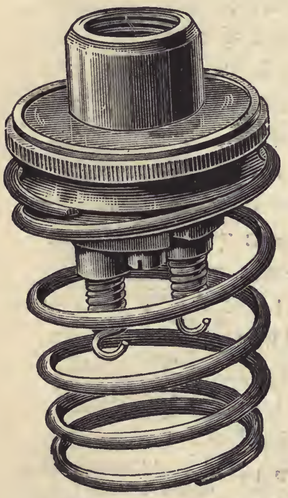


Fig. 47.—Showing a stronger form of Lamp-Holder, for Looped Lamps.

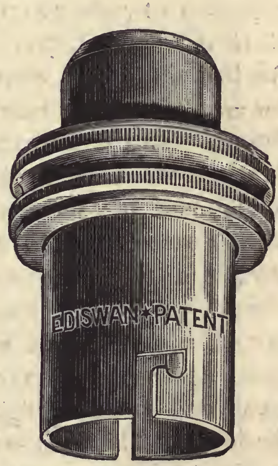


Fig. 48.—Lamp-Holder for Capped Lamps.

kink of the knot is almost sure to cause the small wires, of which the flexible cord is composed, to break one by one, and finally put the lamp out. A fault of this kind, also, is not an easy one to find. The holders most generally used on board ship have been fitted with central contacts, as will be described.

Fig. 47 shows a modification of the Swan holder, the

body of the holder, however, being of metal instead of wood, while both the spiral spring which clasps the lamp, and those which are formed into hooks for connecting to the platinum loops of the lamp, are made very much stronger than other forms of holders. Fig. 48 is a very strong, serviceable holder for capped lamps. It is made all of metal, except a disc of insulating material, slate, porcelain, or some other substance, upon which the contacts of the lamp are fixed. The arrangement for making connection between the filament of the lamp and the supply wires in this holder is as follows:—Upon the disc of insulating material before referred to are fixed two metal plunger contact pieces, as shown in Fig. 50. Each contact piece consists of a small barrel with a spring inside, in and upon which the plunger contact works. A projection on the contact barrel serves to give stability and also to carry the screw for the branch supply wire to connect to. The top of the holder carries a female thread, into which any bracket, pendant, or other fitting may be screwed. The branch wires, which may be either each a single wire of No. 18 or 20 gauge, covered with indiarubber, or a flexible cord consisting of two separate conductors, each consisting of a number of very small wires stranded together and overlaid with indiarubber and then with cotton or silk, are led through the inside of the bracket and through the holes in the insulating disc to the contact screws, so that they are quite out of sight, the bracket or other fitting being made of tube for the purpose. The writer rather prefers the flexible cord for wiring brackets and holders, as it is termed, to single insulated conductors, as the former are much more easily manipulated in the process of wiring,

and, in addition, though the insulation of the separate conductor is better than that of the flexible cord, it is much more liable to be damaged both in drawing through the tube, and from the vibration of the ship afterwards. A single wire is also more easily broken by kinking than the flexible strand made up of a number of small wires. Great care must, however, be taken in making connection to the contact screws. The insulating disc of the holder being necessarily very small in diameter, to correspond with the collar of the lamp, very little room is left between the two contact pieces, so that if the end of a connecting wire be left long, it may touch the other contact, producing what is technically known as short circuit; that is to say, a path for the current by means of which it may avoid the filament of the lamp. Such a connection, as already explained, leads to considerable heating, and often to partial destruction of the holder. It may even happen that a holder will test all right when fixed, and the lamp will burn well for some time, but if a small end of wire has been left over from one contact screw, or the screw itself not properly tightened up when the connection is made, in course of time the end of the wire, or the wire itself, may work over to the opposite contact, with the results that have been explained. In connecting up these holders also, and in fact all holders in which the connecting wires are hidden from view inside the body of the holder, be very careful to use well-insulated wire, and let the insulating material be of a substance that will not easily crack. Be very careful also to exclude damp and grease.

In the best holders of this type there are two separate holes in the insulating disc for the connecting wires, one for each wire. This helps to ensure that the two wires

are kept separate. In some cases, however, these holes are very small, so that the connecting wires have to be taken through naked. In such a case be very careful that the wires are not bared beyond the holes on the bracket side, as otherwise, if they happen to be loose, you may have a connection between the two there also, with its attendant troubles. The same remarks apply to those holders in which the two connecting wires are brought through one hole in the centre of the disc. Be very careful only to bare a sufficient length of each conductor, whether single or strand, to turn comfortably round under the connecting terminal screw. If you bare a longer length you may have the two wires in contact as before.[1]

Fig. 49 shows a holder similar to Fig. 48, but arranged for suspension from the beams of the deck overhead. It would probably not be of much use on board ship, except in places where it has plenty of room to swing about—as, say, over the saloon table. The writer believes that the uniform practice has been to make electric lamp fixtures as rigid as possible on board ship; but it is probable that some hanging lamps would do good service, and would probably stand better in such places—as over the saloon table, etc., where they would not be liable to be knocked, than rigid fixtures.

The old paraffin lamps swung over the mess tables rarely meet with any accident. In fact, experience in sea-going ships would rather point to the adoption of this class of fitting wherever there is room for the largest swing in the heaviest sea-way. As marine engineers well know it is the ship which moves, and not the lamp

[1] In the latest type of lamp holder, the connecting wire passes into a hole in the base of the plunger, and is held there by a screw.

or other suspended fitting; the latter only moving when the ship gives a very sudden lurch, say when struck by a heavy sea. The question, therefore, becomes one of strain. That class of fitting is surely best which allows the least strain to be brought upon the connecting wires and contact pieces, as it is there that faults will occur; connecting wires break under strain, and a spark may

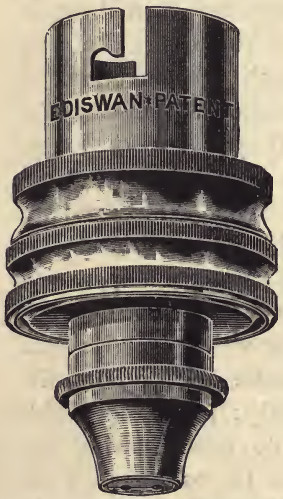


Fig. 49.—Metal Lamp-Holder, for Pendant Capped Lamps.

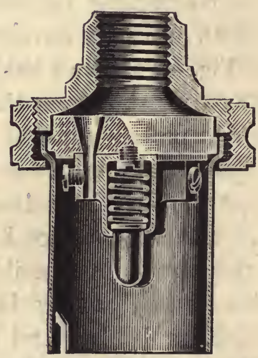


Fig. 50.—Section of Central Contact, Collar Lamp-Holder.

pass across the break. A contact plunger may become bent ever so little by strain, so that it refuses to work in its barrel, with the result that the circuit is again broken, and a spark may pass across the break. In either case not only would the lamp go out, but probably the holder itself would be so seriously damaged by the heat as to be practically useless. The writer believes, there-

fore, that the lamp and shade swinging gracefully overhead where possible, would not only give light where most wanted, but would also give less trouble in maintenance.

In both lamp-holders shown in Figs. 48 and 49 the lamp is fixed in its holder by means of a bayonet joint.

Two small pins are placed in the collars of the lamps at opposite ends of one diameter. The pins on the collar of the lamp are brought in line with the slots in the tube of the lamp-holder, the lamp gently pressed home and turned round till the pins engage in the recesses provided for them.

To remove a lamp from its holder the lamp is gently turned to the left till the pins are opposite the slots in the tube, and then carefully drawn out.

For single contact lamps, the holder has only one metal plunger fixed in the centre of the tube. The base of the lamp has one central plate to correspond, the body of the lamp-holder and the brass collar of the lamp forming the other connection.

Fig. 51 shows what is termed the acorn socket-holder, from its resemblance to the well-known seed of the oak. It is intended for the Edison screwed terminal lamp, shown on p. 126 (Fig. 39). The inside of the holder has a female screw thread of the same pitch as that on the lamp, and, as already explained, forms one side of the supply circuit, the thread and holder itself being of metal. In the base of the socket is a small spring, forming the other supply connection; and it will be remembered that there is a projection upon the top of the collar of the lamp, insulated from the screwed portion, which is arranged to come into contact with this spring, so making the two connections simultaneously. The outer rim of the

holder was at first made of vulcanite; it is now made of porcelain, as it was found that the heat from the lamp destroyed the vulcanite. This holder, with the screwed socket, undoubtedly forms a good support for the lamp, if the two threads are fairly accurate with each other, as the holder has a good grip of the collar; but it is doubtful if this form of lamp and holder is so suitable for ship work as others that have been described. There

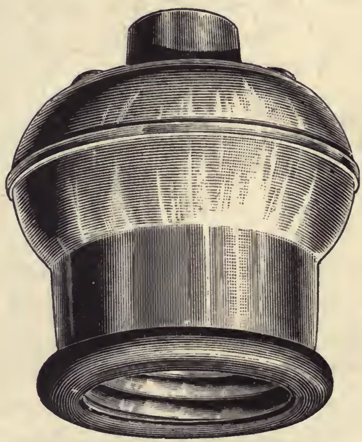


Fig. 51.—Acorn Socket-Holder.

are two weak points in the combination. The central contact depends upon the spring being firmly pressed against the stud-like projection on the lamp itself. Should the screw work back, as, unfortunately, screws do when exposed to vibration, the contact may become intermittent, with the result that a spark may pass between the two, giving rise to trouble as before. The writer hopes to deal very fully with this matter of sparking later on. It is one of the most important

phenomena connected with electrical engineering, and often one of the most troublesome, the great trouble it brings being mainly due to the intense heat developed whenever a spark passes. The other weak point in the screwed lamp and holder is, of course, the possibility that if the screw does work back the lamp itself may drop out and break. This would not be likely to take place with any lamp constantly in use in a prominent place, as the light would be extinguished and the fact noticed long before it could drop out of the socket; but with a lamp in a position where it was not much used—as, say, in a store-room—such a case might happen. In fact, the lamp-makers do not recommend their screwed terminal (as they call the collar) where there is much vibration. The acorn socket is usually fitted with a female screw at the top, to gear with the male screw on the end of a bracket.

Fig. 52 shows a similar lamp-holder to that shown in Fig. 51, but with the addition of a tap switch, so that the lamp can be turned in or out at the holder. In the writer's opinion the use of this form of switch-holder or, in fact, of any form of switch-holder, will die, and is rapidly dying out, except for special cases. Its introduction was not a very wise imitation of the existing gas fittings. Because it is usual to turn a gas cock in the immediate neighbourhood of each individual burner before lighting the gas, it was thought that consumers would like to have the same arrangement with electric lamps. There is, however, no advantage in having the switch attached to the lamp-holder. One of the great conveniences of the electric light is that the lamp may be at the mast-head and the switch in the captain's cabin if you wish;

or, to come to more general experience, the lamp may be out of reach and the switch close to your hand.

In addition to this it is difficult, within the limited space allowable in the lamp-holder, to provide working parts to the switch of proper mechanical strength; and, further, in case it is necessary to change a lamp-holder with the current on, the dynamo running, as it may be,

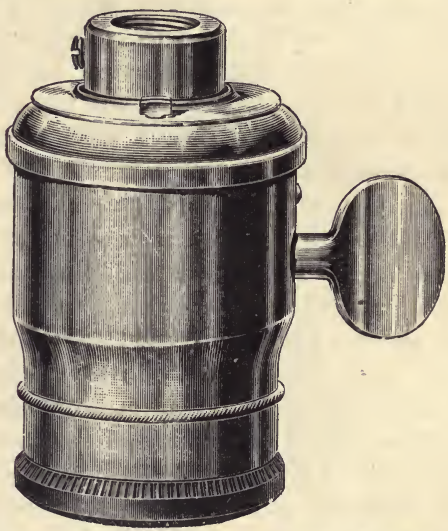


Fig. 52.—Acorn Lamp-Holder with Tap Switch.

you have no means of cutting off the supply to the individual lamp while you are making the connections, and are very liable to get a connection between the loose wires, giving rise to a blinding flash right in your eyes when you break the connection. By placing the switch away from the lamp you can make your connection without any of these difficulties. The switch-holder

is sometimes used with lamps attached to standards that are placed on the table.

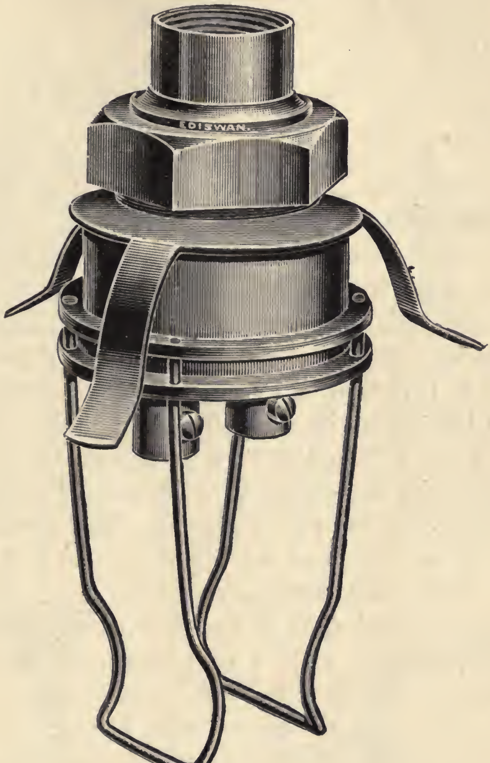


Fig. 53.

Fig. 53 shows the form of holder now used with high candle-power lamps.

After the lamp-holders come the other necessary fittings, such as brackets for their support, the reflectors to

throw the light down where it is most wanted, shades to deaden the light where it might otherwise be too bright, and to hide the blackened glass of the lamp during the day. Brackets and supports are the most important of these fittings. For sea-going ships these require to be made strong and with a certain amount of flexibility, so as to give to the working of the ship. Modern iron-built ships do not work as much as the old type of wooden ships, nor do steamers have such heavy strains as the old sailing vessels used, except in very heavy weather; while few of the latter, if any, are fitted with electric lights. Yet there is still a good deal of strain, particularly from the vibration of the main engine. To meet this the writer's view is that fittings should not be too rigid, so that they may be able to accommodate themselves to the motion of the ship; that, however, does not appear to have been the view of those who have fitted up most of the ships that have been built since electric light came into vogue. Their idea has been to have everything as firm and as rigid as the main engine blocks. Hence the fittings, shown in Figs. 54 to 57, have found a good deal of favour with them, for saloon lights in particular, and in many cases for cabin lights. The fittings consist of strong and more or less ornamental brackets, made out of bronzed tube, having stout flanges for securing to the bulkhead, and to support the globe which shades the lamp. In the bracket shown in Fig. 54 the tube makes a graceful curve from its base, raising the globe to the latter's level. In Fig. 55 the tube is cast with its base at right angles to the flange which supports the globe. In Fig. 56 the base and the flange for the globe are parallel with each other, this fitting being

intended for attachment to the beams where there is room. In Fig. 57 the tube bends round gracefully till

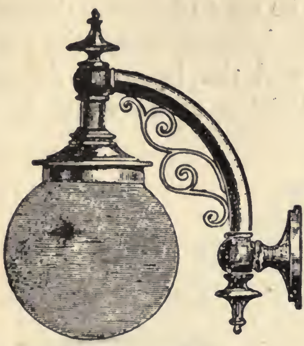


Fig. 54.—Showing Curved Ornamental Bracket, for use in the Saloon, with ground Glass Shade.

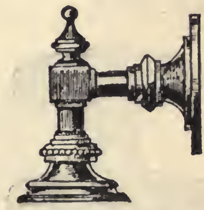


Fig. 55.—Showing Bronze Bracket, with Shade carried at right angles to the Base, without Shade.

the globe flange is at right angles to the base of the bracket, the former being, in this case, below the latter.

Fig. 56.—Showing Ornamental Bronze Bracket, with Shade Carrier for overhead; generally used in the Saloon for Lamps fixed over the Table.

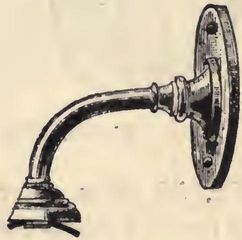


Fig. 57.—Plain Carved Bronze Bracket, with Shade Carrier.

In each of these forms the supply wires are threaded through the inside of the tube and pass from there to

the holder; this latter screws on to a hollow-made screw provided for it in the centre of the flanged shade carrier. Which of these fittings should be used of course depends upon circumstances; the height between decks, the taste of the owner or the captain, and the bulkhead decorations, all go to modify the decision as to which form shall be used.

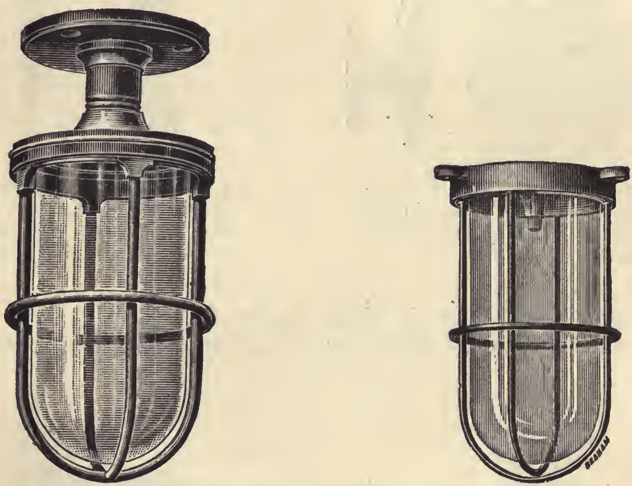


Fig. 58.—'Tween Decks Guarded Fittings.

Fig. 58 show other forms of lamp fitting that are very useful for between decks on board emigrant ships, and for the forecastle, cook's galley, and other places. They consist of strong, brass-flanged collars, arranged to hold a glass cover the shape of an inverted diving-bell, the glass itself being protected by the stout wires shown. As the wires cut off some of the light given by the lamp, these fittings can only be used where it is not of so

much importance to have a good light as to have a light at all times, without fear of accidents, wilful or otherwise. None of the pendant lights, for instance, that will presently be described, would be suitable either for the forecastle or the steerage of a passenger ship, though they have even been used at collieries. Skylarking would soon make short work of them; but the fittings

Fig. 59.—Bulkhead Fitting.

shown in Fig. 58 should, and does, stand the strain well, if properly made and fixed.

Another fitting that has been used on board ship is shown in Fig. 59, and is termed a bulkhead fitting. It is intended to be screwed right up against the ship's side or any water-tight partition, so as to take up as little room as possible. It may even be let into the bulkhead, so that its wire guard is just flush with the woodwork.

The object sought to be attained in this fitting is the same as in that shown in Fig. 58, viz. the occupation of small space combined with freedom from breakage.

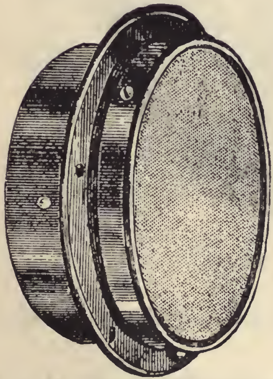


Fig. 60.—Bulkhead Fitting for Lighting two Cabins with one Lamp.

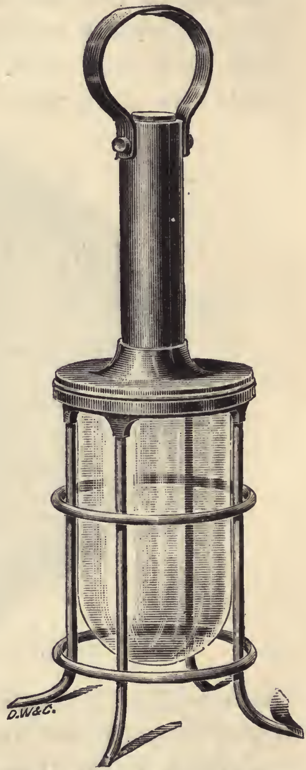


Fig. 61.—Guarded Portable Lamp Fitting.

The wire front is sometimes fitted with a lock and key, so that it may only be opened when it is required to change the lamp.

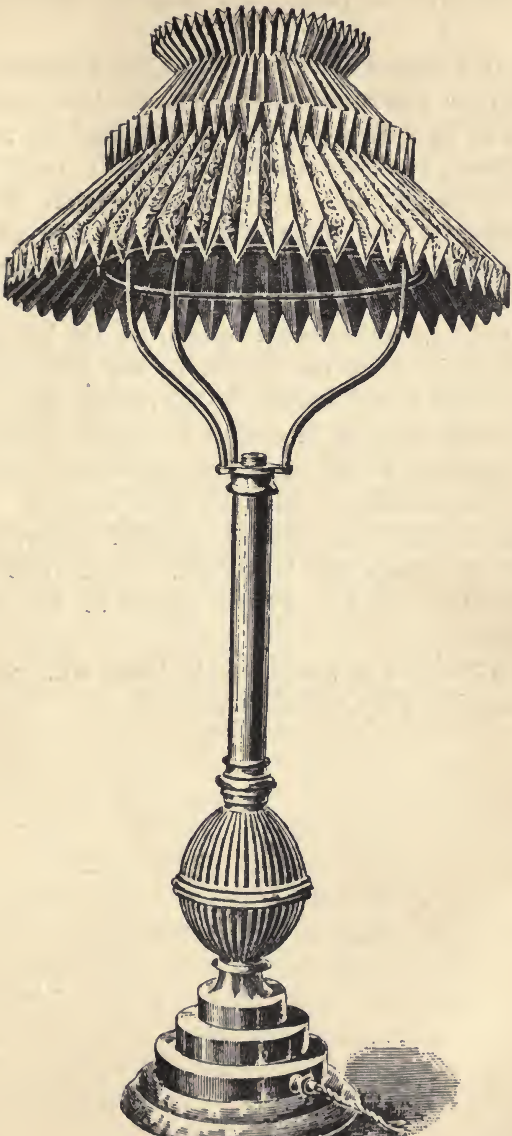


Fig. 62.—Reading-Table Lamp.

Fig. 60 shows another form of bulkhead fitting designed to economise lamps. As will be understood, it is fixed in a hole cut in the bulkhead to receive it, say between two cabins, the flange shown being screwed to the woodwork, and the light showing on either side. This fitting is most frequently used where a permanent light is required. It would hardly do for cabin lamps, except in special cases—as, though it could be arranged for a switch in either cabin to turn on the light, neither could turn it off if the switch in the other cabin was closed, which would hardly be convenient for an officer who wanted to turn in during his watch below, if his light happened to belong to the next cabin too, and the owner of that cabin to want the light burning.

Fig. 61 shows a portable guarded fitting intended for portable lamps, for holds, etc. A flexible cable is attached to it and a switch placed at the point of connection.

Fig 62 shows a reading-table lamp, with silk shade. The lamp is fed by a flexible cord.

CHAPTER V.

SWITCHES AND CUT OUTS.

NEXT come switches and fuses or cut outs, as they are termed. The office of the former is to control any individual lamp or group of lamps, by allowing the current to pass or cutting it off at will. The term, like a good many of those that have come to us from the early pioneers in applied electricity, the telegraph engineers, was originally borrowed from the apparatus used on railways for the purpose of diverting the course of a train from one line to another. Switches used in telegraph work are often made to change the direction of the current from one wire to another, from working one apparatus to another. As they were occasionally used for breaking the circuit also, the term has been handed on to electric light apparatus. In the latter, too, we occasionally have switches to divert the current from one lamp to another, or to connect a lamp or group of lamps to either of two or more sources of current.

The simplest form of switch, that which merely makes and breaks the circuit, causing the lamp to burn or the reverse, consists of two or more metal parts, one of which is movable and the others stationary. The whole of the parts are mounted together on a base of insulating material, such as hard wood, vulcanite, slate, or porcelain.

The earlier switches were all mounted on hard wood, and some of them are still doing good service; in fact, in the writer's opinion, the all-round qualities of good hard box or ebony are superior to those of either porcelain or slate. Wood, however, fell into disgrace, because that used in the early days of electric lighting often was not hard. It was sometimes soft, readily absorbed moisture, and thereby lost part of its insulating properties. Further, many of the early switches were badly constructed, not conforming to the principles that will be detailed later on, so that large sparks were often present, which charred, and in time burnt up, the wood base altogether. They were also constructed in many instances, so that the spark, which was in some cases not easily avoided, passed close to or even through the wood base. In the case of large switches also, if the wood bases on which they were mounted were not thoroughly well seasoned, they were very apt to warp, and by throwing the working parts out of gear with each other, to produce sparking and bad working generally. Slate overcomes a great many of these difficulties, and is coming into use very much; but it is not so easy to work as hard wood, and is very apt to split into sheets. It is also not such a good insulator as either hard wood or porcelain, but this is not of so much importance in the case of most switches, especially those used on board ship, as the voltage present within the switch itself is usually small; the resistance of the lamp or lamps and wires using the initial voltage up on its way to the switch.

The great feature in favour of slate bases for switches and other apparatus is their incombustible nature. Por-

celain came into favour principally from the fact that no other substance could be found to stand the high tension currents when they first came into use for central station lighting some years back. In those days the high tension distributing current, which was supposed never to get near the consumer—and in these days never does —being transformed to low tension before it reaches the consumer's service, used sometimes, like a naughty boy, to be found where it had no business to be, the result being heavy sparking or "arcing" between the parts of the switch, and that not even slate would stand for long. The land insurance companies having also specified for porcelain in all these cases, while the material lends itself very readily to decorative purposes, it has been largely adopted. In the writer's opinion, however, porcelain is not adapted for ship work, and there is no good reason for its use, except where decoration is the object to be obtained. It is too brittle for the rough usage it must receive, almost of necessity. Many porcelain switches break even from their own snap action when in use. As also the voltage used on board ship is almost invariably low, 65 volts or thereabouts being the favourite, there is no danger to be apprehended from the use of slate, or of good dry hard oak or ebony. Porcelain or enamelled slate is now universally employed for mounting switches.

The requirements of a good switch are:—(1) That its metallic parts shall contain sufficient metal to carry the current it is designed to control, under all circumstances, without heating. In the smaller switches, even those that are badly designed, this condition is necessarily fulfilled, because it is almost impossible to work, and to hold pieces of metal upon slate or porcelain that are not

of the required strength, so far as the current is concerned. The Board of Trade rule for cables, which is also a good working guide for switches, is that not more than 1000 ampères shall pass through a square inch of copper, and that the currents passing through smaller conductors shall not exceed the same proportion. The electrical resistance of brass is higher than that of copper; but, on the other hand, the metallic parts of a switch have nearly always a better opportunity of cooling than cables, as the former are more or less exposed to the air, while the latter are enveloped by their insulating covering. By this rule, the working parts of a switch to control a single lamp of 16-candle power should be only of wire or spring equal to No. 20 standard wire guage, which it would be absurd to make any but a toy switch of. With very large currents, however, the strength of metal to fulfil the above conditions works out to very heavy figures; and as the weights to be moved and to be supported are large, mechanical requirements become necessary, which tempt switch makers to reduce the metal in the working parts. In a switch, for instance, which was designed by the writer some years since, and made by his firm for metallurgical purposes, to control a current of 3000 ampères, the slate base upon which the working parts were mounted weighed over 1 cwt., while the metallic parts themselves weighed over 3 cwts.

The next requirement of a good switch is that the bearing surfaces between the moving and stationary portions shall be of sufficient area to carry the current without undue heating, and without introducing an unnecessary resistance into the circuit. This requirement is, perhaps, the most important of all. The points

at which the metallic continuity of an electric circuit is broken always offer a higher resistance to the passage of the current, and often a very much higher resistance than the conductors on either side of them. The causes for this are partly mechanical and partly electrical. Two surfaces that are apparently in good metallic contact are often only touching at certain points, so that the sectional area available for the current to pass through is very much less than the actual size of the surfaces would indicate, thus leading to increased resistance. The electrical reasons are that a film of dirt or moisture is often present between the surfaces, and that this moist film, with the two metal surfaces, which are invariably in a different physical state, one, perhaps, being harder than the other,—one having its grain across that of the other,—forms a galvanic battery which may set up an EMF in opposition to that of the working current. This is also one point in which there is a temptation to cut down in the large switches, viz. the provision of sufficient contact surface, as it requires more metal to properly carry out. In some of the earlier switches also the same defect was to be found in even some of the smaller ones, and at the present time there is too great a tendency to put a switch to control a certain current that is clearly too small if proper allowance for the surface contacts be made.

Another requirement of a good switch, and one that follows closely upon and partly depends upon the last requirement being fulfilled, is that the contact surfaces shall be so arranged as to always keep clean. One of the difficulties attendant upon ensuring this is, a spark always passes between the contact pieces at the moment

of breaking circuit, when the light is turned off. The damage done by the spark to the contact pieces depends upon other details of construction that will be described later on. But no matter how carefully the switch be designed, nor how carefully it is used, the spark invariably leaves its mark behind it, in the form of a burn, or of dirt. If the working parts of the switch are small in proportion to the current they have to carry, particularly in the matter of the contact surfaces, the continued sparking, where the switch is much used, will destroy the contact surfaces entirely, by gradually burning them away; and the rate of deterioration will be very rapid after a certain limit is passed, as the surfaces between which the spark has to pass will become smaller and more irregular every time the switch is used. In fact, it is no uncommon thing, with badly designed switches, such as have been described, for the contact parts to be fused together by the spark, especially when the metal base of the switch is very small in proportion to the current it has to carry. For this reason some plan is usually adopted of making the working parts of the switch clean themselves, the dirt left by the spark being rubbed out the next time the light is turned on. Such an arrangement is termed a rubbing contact, and is another old telegraphic device. All the contact troubles that are met with in electric light apparatus are also met with in telegraphic, telephonic, and electric bell signal work, and in an equally troublesome form, though the sparks there are very trifling in size and volume compared to those met with in electric light work. A badly speaking telephone very often owes its failure to the presence of dirt between the contact surfaces of its

switch, due to the spark before mentioned. Whenever possible, then, designers of switches arrange that some portion of one side of the metallic contact shall rub the whole length of the other metallic contact surface before the switch handle bar comes to rest, in the operation of turning on the light. This is usually effected by making either the whole of one contact surface part of a spring or bar which gives, or by attaching a spring to one of the contact pieces in such a manner that the moving contact bar in overcoming the tension of this spring, in order to get into its place when "On," is caused to rub against the other contact piece. Another plan which has also been used with success is by arranging that the first and last contacts are made with one set of surfaces, while the actual working current passes by way of a second set. In this arrangement the moving bar makes contact first with a spring in connection with the portion of the circuit it is desired the current shall pass through, and later on, when the contact bar has reached the end of its motion, this spring is pressed into contact with another metallic piece, which is so arranged that the current can now pass by way of the spring and the second contact piece. In breaking circuit, the spring before mentioned first leaves the stationary contact piece, owing to the motion of the contact bar having released it, but the circuit is not yet broken. It is broken later when the contact bar leaves the spring, as it will do after moving farther, and the spark that must do so passes between the two latter, while the surfaces of the spring and fixed contact piece, which are opposed to each other, remain clean.

Another requirement of a good switch is that it shall

be so designed mechanically that its contact surfaces do not get into such a position that they only touch loosely, or not at all, when the circuit is closed. If such a thing does happen, either the lamp or lamps controlled by that switch will go out, or will burn dull or intermittently. If the contact be broken entirely, of course no current can pass; but if the contact is made loosely, the higher resistance offered by the loose contact, as already explained, will prevent the proper current passing to the lamp, which, therefore, cannot give out its full light. Besides this, also, every jar of the ship is liable to jerk the contact surfaces apart, and to cause a spark to pass. Such a condition of things will arise in those switches in which a centre contact-bar works in a hole in the wood, slate, or porcelain base as a bearing, and moves over or between two contact pieces, if either the base or the contact bar wears away, so as to become loose, or the former gets broken or chipped. The same result will be arrived at if the wood upon which the switch is mounted is unseasoned, and warps. For the above reason the moving parts of all switches of this kind should work in and on metal of the same nature as themselves, and there should be a provision in the construction of the switch, for automatically taking up the wear of the two surfaces; say, by placing a flat spiral on the spindle of the switch, the spring tending to pull the two surfaces together. Since, as described above, the spark which passes between the moving and stationary parts of the switch has such an important bearing on the life and efficiency of the switch, every effort is made by designers and makers of switches to reduce the volume of the spark itself, to spread it over as large a surface as possible, and also to render its actual

duration limited. As already indicated, the volume of the spark and the surface over which it is spread are provided for by giving both moving and stationary parts not only plenty of metal in proportion to the currents they have to carry, but also by giving them plenty of bearing surfaces in contact with each other. Still, if these requirements have been fully provided for, a switch may work very badly after being a short time in use, if the spark—or arc—is allowed to be maintained for any length of time. In order to avoid this, the plan is now almost always adopted of arranging that it is impossible for the switch to be left in any position but right on, or right off. In a great many of the earlier switches, the designs of some of which were taken from the old gas and water cocks, it was left for the user to turn the handle bar as far as it would go, just as he had been accustomed to turn his gas-cock until brought up by the stop. Unfortunately it was found that the user, not having before him the same feeling that he has with gas or water, that they will waste if not fully turned off, was apt sometimes to leave the switch handle in the position into which he had moved it when the light went out. This position, however, was the most favourable one in many cases for an "arc," as it is termed, a bridge of flame, to be set up between the two parting surfaces; and if this arc was allowed to burn itself out, very serious damage was done to the switch, as it would only cease to burn when a sufficient quantity of the opposing metal surfaces had been consumed, to enable the resistance of the arc to become too great for the EMF present to maintain it. In some switches, also, the possibility of an accident of this kind happening was very

much increased by there being nothing to show when the switch was right on or right off. The result of all these troubles was the birth of the "snap" action, or quick breaking switch. There are many patterns of this switch, every maker having his own special fancy, but the principle is the same in all. Immediately the moving contact bar is released from its hold in the fixed metal contact, a spring of some form comes into operation, which pulls it right back to its position of rest when the light is "OFF." In one class of switches, which have met with much favour on shore, the moving contact bar works independently of the handle after the latter has carried it a certain distance, the spring before mentioned then taking charge, and causing it to fly back to the position of rest. In another large class of switches the spring only comes into operation after the hand has left the handle bar, though, of course, it assists the hand in bringing the contact bar away. With most modern switches the result is that the contact bar now leaves its opposing contact piece so quickly that whatever spark is formed is of very short duration, and therefore does little harm.

The respective merits of the "loose-handle" switch, as those are termed in which the spring moves the contact bar independently of the handle, and of the fixed handle switch, are well worthy of attention. The action of the loose handle switch, when well made, is very pretty and very taking, and it ensures absolutely that there shall be no chance of a spark of any duration forming, say from children playing with the switch, as it is impossible to leave the contact bar in any position but that of complete good contact, or the position of rest when light is

"Off." On the other hand, beautiful as are the details of the arrangement of the loose handle, they weaken the working parts of the switch, render the construction more complicated and therefore more expensive, and the snap action wears the switch itself out. In the case of porcelain based switches this is particularly noticeable, the base and handle often being broken, so that the switch is rendered quite useless in a very short time, owing to the jar of the contact bar in flying back each time the light is turned off. The action of the fixed handle switch is not so absolutely certain with regard to the spark, but it is practically so, and its greater strength and simplicity render it less liable to get out of order and less expensive to construct.

Another important requirement in a switch is, that the metallic parts when at rest in the position of "Light Off," or when moved into that position on turning the light out, should not be within sparking distance of each other. It is important that the metallic contact bar should not only be out of sparking distance of any part of the switch to which it can bring a connection that will allow a current to pass, but that it shall not be able to get into such a position when flying back on being released by the loose handle, as it is obvious that under the impulse furnished by the spring some portion of the contact bar may go further than its proper position of rest. The sparking distance in this and other cases is, of course, determined by the EMF present.

Fig. 63 represents a "plug switch," the simplest form that is made. It consists of two blocks of metal, or rather of one block sawn in two, with a hole drilled between the near surfaces for the reception of the metal

plug shown. The two blocks are mounted on a piece of vulcanite, wood, slate, or porcelain, according to the work for which the switch is intended, and the plug, which is made of a taper form, is also fitted with a handle of insulating material, as shown. This is not a good form of switch, as it is very difficult to prevent an "arc" being formed between the two surfaces on withdrawing the plug. In using a switch of this kind it is of the utmost importance that the plug should fit tightly into the hole provided for it, as otherwise sparking may be set up with any vibration that takes place. In order to ensure that the taper surface of the plug shall grip the two surfaces of the metal blocks on each side, it is usual to give the plug a quarter-turn to the right on putting it into its hole, and a quarter-turn to the left on removing it. It will easily be understood that if an "arc" is set up on removing the plug, either between the surface of the plug and that of either metal block, or, as more frequently happens, between the surfaces of the metal blocks themselves, the hole will be thrown out of shape, both by actual combustion of the metal and by the warping due to the intense heat, and that this will lead to further sparking and more trouble. In the illustration, connecting pieces are shown attached to the metal blocks by means of screws passing through the insulating base. This arrangement is very convenient for large

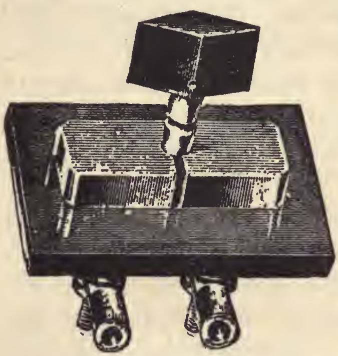


Fig. 63.—Plug Switch.

wires, but for small ones it is not necessary, as a screw tapped into the top surface of each metal block is quite sufficient. The screws shown underneath also make the switch not so easy to fix, as a wood block or some other support must be provided that can be recessed to make room for the screws.

Fig. 64 shows a simple form of bar contact switch. The pattern shown is intended for use with only one or

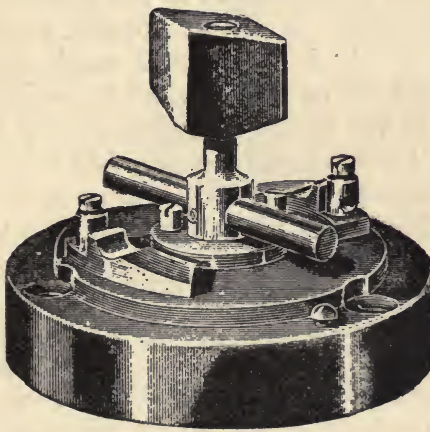


Fig. 64.—Simple form of Bar Contact Switch.

two lamps. The base, which may be made of wood, slate, or porcelain, has a flange turned, as shown, to take the cover, which is made to be held on with screws. To the metal contact pieces on each side are attached terminal screws for the connecting wires, the latter being carried through separate holes in the base provided for them. It will be noticed also that, in this particular switch, the fixed contact pieces present inclined planes to the motion of the contact bar, which is then allowed to fall into a

recess made for it on each side, the object being to lock the switch while the circuit is closed. The movable contact bar consists, as will be seen, of a turned spindle working in metal guides mounted on the base, and provided with a wire cross-bar of sufficient length to reach the two fixed contact pieces, the handle being of insulating material as usual. There will be a spring underneath the base of the switch, whose office is to pull the spindle of the contact bar down, and at the same time to allow it a certain amount of motion upwards, so that the bar may travel up the inclined planes and be firmly locked on falling into the recesses provided for it by the downward pull of the spring. The same spring which pulls the contact bar down may also be made to pull it away from the stationary contact pieces as soon as it rises above the ridge of the recess in which it has been locked when turning the current off. This is a very ingenious and a very simple form of switch, but there is always the danger that the pulling-down spring may lose its tension, when the contact made in the recess would become loose; also that the form of the recess may be altered by the actual combustion of the metal, caused by the spark that is formed on breaking circuit, and, as before explained in connection with the plug switch, by the warping action of the intense heat generated.

Figs. 65 and 66 show another form of switch, in which the contact bar is also locked when the circuit is closed. In this form the fixed contact pieces are made in two parts—one flat piece upon which the moving contact bar slides, and a spring, bent into the position shown. The latter is so held that the moving contact bar is obliged to force it up, in order to get into its

proper position, and thus locks itself when there, by the pressure of the spring, whose tension it has overcome. The moving contact bar is held on a central spindle, to which also the porcelain handle is attached, and a spring is provided to throw the bar back clear of the fixed contact pieces as soon as the motion of the handle has released it from the locking spring before described.

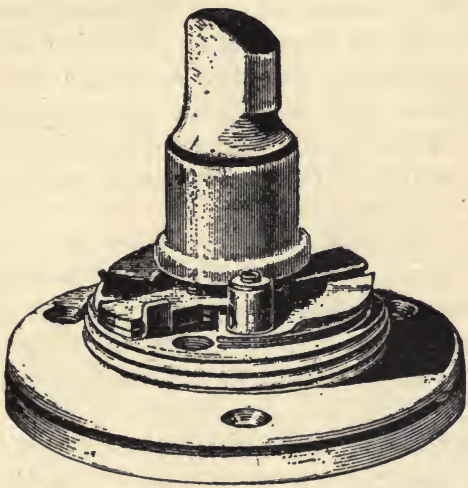


Fig. 65.—Showing another form of Double Contact Switch, with Central Contact Bar.

The spring which throws the bar clear may be either a spiral spring working on the central spindle, or a spring shaped something like a lady's hair-pin, with the points spread out; or it may be a spiral spring, carried under the base of the switch, attached to a pin in the contact bar, the pin working in a slot provided for it in the base. This last form of spring is not a good one, as the slot required in the base of the switch for the pin to

which it is attached to work in necessarily weakens the whole thing; added to which its action is not so sure nor so even as either of the other forms. The switch itself, if well made, is a remarkably good one. One of its weak points is—the upper part of the fixed contact piece, unless made of good hard brass, may bend up in course of time, and there will then be no locking pressure on the moving contact bar, with the result that the latter may be pulled out of contact by the action of the spring that is intended to pull it clear of the fixed contacts when released, or, if it does not go as far as that, the looseness of the contact between the moving bar and the fixed pieces of metal will give rise to sparking with all its attendant troubles.

In Fig. 66 the moving contact bar has only one arm, and the circuit is completed, not by connecting the two fixed contact pieces together by means of the moving bar, but by connecting the single fixed contact piece with the central spindle, or the guide plate in which it works.

This switch is not so good as that shown in Fig. 65, though many of this pattern have been used, because of the element of uncertainty in the connection with the central spindle. The radial contact bar usually forms part of the same casting with the central spindle, but as connection to the wires is only obtained by means of terminal screws attached to plates which cannot be cast on the spindle, and can only make connection with it and the radial contact bar by means of surfaces bearing upon each other, it follows that if these surfaces do not fit closely to each other, or if their wear is not taken up automatically, as, say by a flat spiral spring underneath

the base of the switch, a loose joint will be formed between them, which will lead to sparking and possibly to a disconnection.

The switches shown in Figs. 65 and 66 may be made with loose or fixed handles, and the latter may be of porcelain, wood, or vulcanite. Where the handle is loose, as already described, it is very apt to be broken when

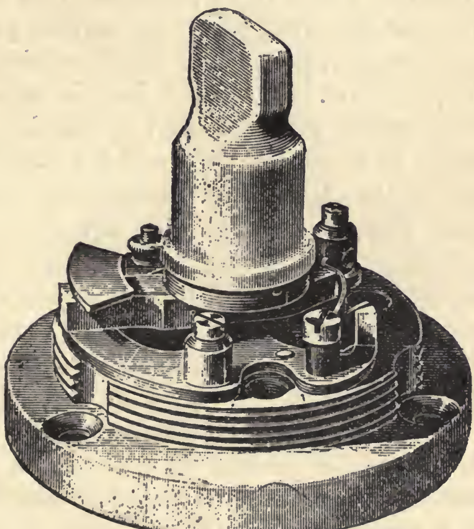


Fig. 66.—Showing a Switch similar to Fig. 65, but with Single Contact and Radial Contact Bar.

turning the light off, by the violence of the impact of the contact bar against its stops.

It will be noticed that the moving contact bar in Fig. 65, which is in the position of "LIGHT OUT," rests against a stop consisting of a small metal bracket, formed by turning up a portion of the plate upon which the

central contact bar works. This is a very simple arrangement, but a very wise precaution, as it prevents the contact bar from flying back to within sparking distance of the opposite fixed contact piece.

It will also be noticed that these two switches, which are intended to be made in either porcelain or slate, have a large flange on the base, in which are the screw holes for securing the switch in its place, and that above this flange rises the disc upon which the moving parts of the switch are mounted, the edge of the disc being threaded to receive the cover. When the base is made of slate the cover is usually either of wood or metal, and is held by screws or by a sort of bayonet joint working round pins fixed in the edge of the base. Some switches on this pattern have been made with a wood base and a wooden cover screwed to the base, but with a thin slate disc mounted on the central portion of the wood base. In the writer's opinion this forms a very good combination. The cover is, of course, in all cases, fitted with a hole for the handle of the switch to protrude through, and it is usually arranged that, when the cover is removed, the handle remains in position, as shown in the figures. With some form of loose-handled switches, however, a special arrangement is made, so that when the cover is removed the handle is also.

Figs. 67 and 68 show another type of switch, also intended for only a few lamps, though they are sometimes used for a good many more. The contact bar in this case is sometimes fixed to the handle, and the latter is sometimes detached, as before explained. The bar itself, in this form of switch, consists of a number of thin strips of hard brass bent into the form shown, the

object being to create a spring within the bar itself that shall tend to pull the latter down on to the fixed contact plates and maintain a firm contact. It will be noticed also that the fixed contact plates are in the form of inclined planes, so that the contact bar in moving over the inclined surfaces automatically tightens itself. The pull-off spring, which throws the contact bar clear

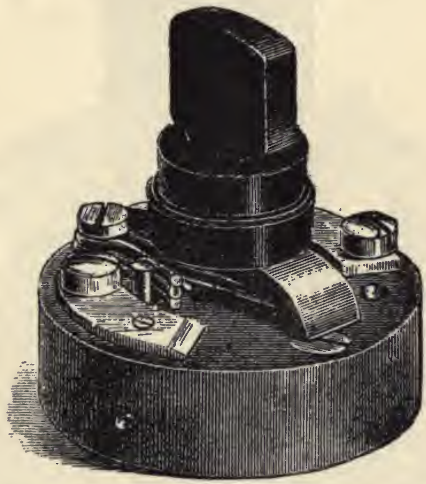


Fig. 67.—Showing another form of Double Contact Switch, with Pull-off Spring, mounted on Slate Base. The Contact Bar is in the position of "LIGHT OUT."

of the fixed contact pieces when released, consists of a series of the ladies' hair-pins or lock springs before mentioned, and they operate by pressing upon a projection under the contact bar, placed there for the purpose, against which they have a good bearing just at the moment when the bar is leaving the fixed contact piece, and a spark would pass if it were not immediately

thrown clear. In this form of switch there is no stop to catch the contact bar when moving into the position of "LIGHT ON," the tightening of the springs of the contact bar itself, when properly made and in good order, performing the office of the stop that is used in some

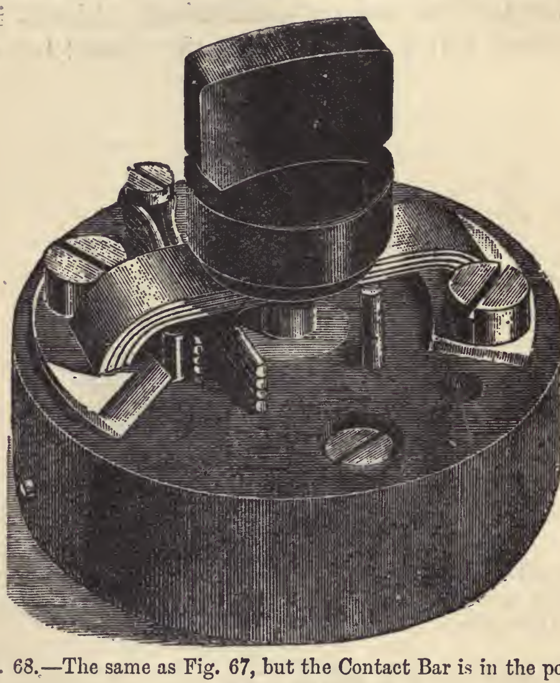


Fig. 68.—The same as Fig. 67, but the Contact Bar is in the position of "LIGHT ON."

other switches, and also locking the switch as well, notwithstanding the pressure of the pull-off spring. It will be noticed, however, that the pull-off spring, owing to its form and the position it assumes when the switch is closed, has very little power then, so that the locking

of the switch has not much to act against in that direction. This form of spring is a good one for other reasons. Its tension is not strained when the switch is closed, as would often be the case with a straight length of coiled spiral used for the same purpose, and exerting its pull in the direction of its length. The great danger with this form of switch is the possibility of the contact bar wearing from continued friction over the fixed contact surfaces, and the wear not being taken up. Another danger is the possibility of the spring plates of which the contact bar is formed losing their form, spreading themselves into a pair of obtuse angles. Should this happen of course the switch would immediately become useless, as the contact bar would no longer perform its office of making connection between the two fixed contact pieces. Should the spring plates of the contact bar lose their form in a small degree, it would probably cause sparking at the contact surfaces and the other further troubles. There is also the possible danger of the V spring, as it has been termed,—the spring formed of ladies' hair-pins,—losing its tension, not from strain, but simply by losing its temper. All springs are, of course. liable to this; but it appears to the writer that this spring, depending as it does for its operation entirely upon the form impressed on it, is specially liable to action of this kind unless very carefully made.

The switches shown in Figs. 67 and 68 are both mounted on slate bases, and have wooden or vulcanite handles. The handle of that shown in Fig. 67 may be arranged to be removed at will, so that the switch is then locked in another sense, viz. that it can neither be closed nor opened without the key. These switches are

provided with either wooden or metal covers. Where metal is used the cover is lined with brown paper, or other insulating material, to prevent the possibility of a connection being made between the fixed contact pieces, by means of the metal of the cover. In the writer's opinion wood covers are by far the best for these switches, as there is very little room for any insulating material inside the metal cover, and whatever is placed there is

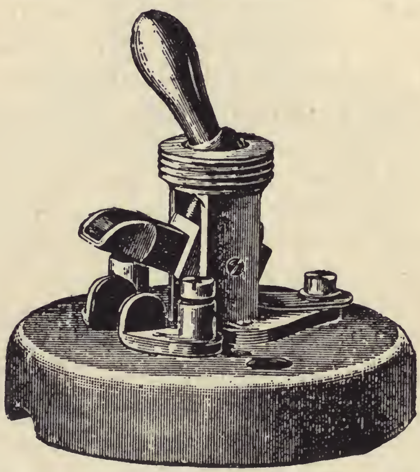


Fig. 69.—Showing Internal View of Tumbler Switch.

almost sure to wear away in time and to give trouble by exposing the metal. Further, if any sparking does occur the insulating material is immediately destroyed by the intense heat generated.

But every other form of switch has now pretty well given way to what are called tumblers or tumlers, from the special action of "On" and "Off."

Figs. 69 and 70 are inside and outside views of the

tumbler switch. The base of this switch is sometimes slate and sometimes porcelain. In larger switches, the "chopper" switch, which corresponds to the tumbler in small switches, is now the favourite, the cover being of metal and fitting over it.

The fixed contact pieces in this case are in the form of two small brackets held to the base by screws, and the moving contact consists of a sort of shoe fitted on the

Fig. 70.—Tumbler Switch.

end of a bar of vulcanised fibre or vulcanite. The bar of insulating material is held at the other end in a metal cramp, which is pivoted between two pillars, as shown. The two pillars which support the pivot of the contact bar also carry a brass collar, the office of which is twofold.

It is screwed on its outside circumference, and on this screw the cover fits. It also forms a sort of guide

for that portion of the apparatus which gives its name to the switch, and which operates it. This is a tumbling handle. When in the position shown in Fig. 69, the handle has tumbled forward, and has allowed the contact bar to obey the pressure of the straight spring shown behind, and its shoe to rise clear of the fixed contact pieces, thus breaking the circuit. To put the switch in the position of "ON," the handle is tumbled back, causing the other part of the bent lever of which it forms a part to force the contact shoe down between the fixed contact pieces.

The weak points of this switch would appear to be:—

The small handle, which, it will be noticed, is not easy to catch hold of;

The possibility of the spring which throws the contact bar "OFF" losing its tension, and therefore failing to release the latter from the grip of the fixed contact pieces;

And the fact that any wear of these portions of the contact pieces which face each other is sure to lead to loose contact and its attendant sparking, it being also certain that such wear will take place.

On the other hand, the switch fulfils many of the requirements of a perfect switch. The connection between the moving and fixed contact pieces remains good, until one of them is worn, or one of the fixed pieces is pushed on one side. The arrangement provides that great desideratum, a rubbing contact, thereby ensuring that the dirt made by the spark on turning the switch off shall be removed next time the switch is turned on. The switch is also neat and compact, and the

"pull-off" is fairly quick, so long as the spring retains its tension.

The author has recently worked out a modified form of this switch, in which a sort of link motion performs the office of moving the contact bar into the positions "ON" or "OFF."

Another instructive point in connection with switches may also be discussed here. Would switches be better with only one break, or with two, as made? It is a striking fact that the earlier switches were nearly all made with only one break, whilst most of those at present in use have two. One great advantage of the double break switch is that the two breaks lessen the energy available for the spark at each. As will be well understood, the spark which passes between the two parts of a switch on breaking circuit obey Ohm's law, just as every other form of current does. Consequently, as the EMF available for creating the spark is independent of the spark itself, depending, in fact, only on the EMF at which the system is worked, the number of coils on the field-magnets, and the extent of the change taking place in the circuit, the more the resistance opposed to this EMF can be increased, the smaller will be the current that can pass. It is well known that the resistance of the air space between the moving and stationary parts of the switch is enormously greater than that of any other part of the circuit of which it temporarily forms a part, and it therefore follows that the greater the number of air spaces that can be created at the moment of breaking circuit, the more will be the energy of sparking decreased. The ratio of decrease of the energy of each individual spark will be far greater

than the simple ratio of the number of breaks created. In fact, it would be possible to eliminate the spark of even a very high tension current entirely, if the number of breaks could be multiplied indefinitely. The principal advantages of the double break switch are, however, mechanical. It is easier to make good metallic contact between one moving contact bar, which takes no part in the action except when in contact, and two fixed contact pieces of almost any pattern, than between a fixed contact and a moving central contact piece which itself forms a part of the circuit, irrespective of its position in connection with the fixed contact piece; and the reason is one of those electro-mechanical problems that are so often met with in all branches of electrical engineering work. The moving contact piece must depend for its connection to the fixed piece of metal, to which the terminal for the connecting wire is attached, upon a surface connection with some portion of that same piece of metal, or with some other piece of metal in connection with it. Now, though a rubbing contact is good where a spring is present to make good the wear caused by the friction of the parts when rubbing over each other, it is bad when this feature is absent, as the inevitable wear must lead to loose contacts, with the attendant increase of resistance and possible sparking.

The disadvantage of the double break switch is the double joint, leading to two possibilities of failure instead of one; but, as will have been seen, this is more an apparent disadvantage than a real one, as the single break switch really has two joints, just as the double break switch has.

Large Switches.

The principles upon which large switches are constructed are exactly the same as those upon which small ones are; the only points that have to be considered especially being the mechanical details involved in providing sufficient support for the heavier moving and stationary parts, and the electrical details involved in providing for the safe passage of the larger spark and the larger currents. These points do not,

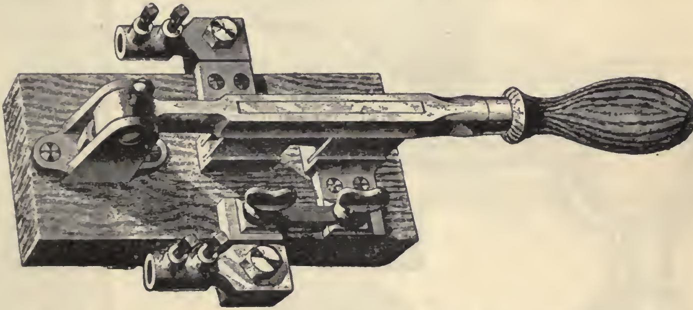


Fig. 71.—Showing American "Chopper" Switch, with Fuse attached. The Switch is shown "Closed."

however, become of serious moment until very large figures are reached, such as would hardly rule on board ship.

Figs. 71 to 73, however, are examples of large switches by different makers, each maker as usual following out his own ideas, and working on certain lines, but with the same principles running through all.

Fig. 71 shows the "chopper" that has been already mentioned, which is a great favourite with the American electric lighting companies.

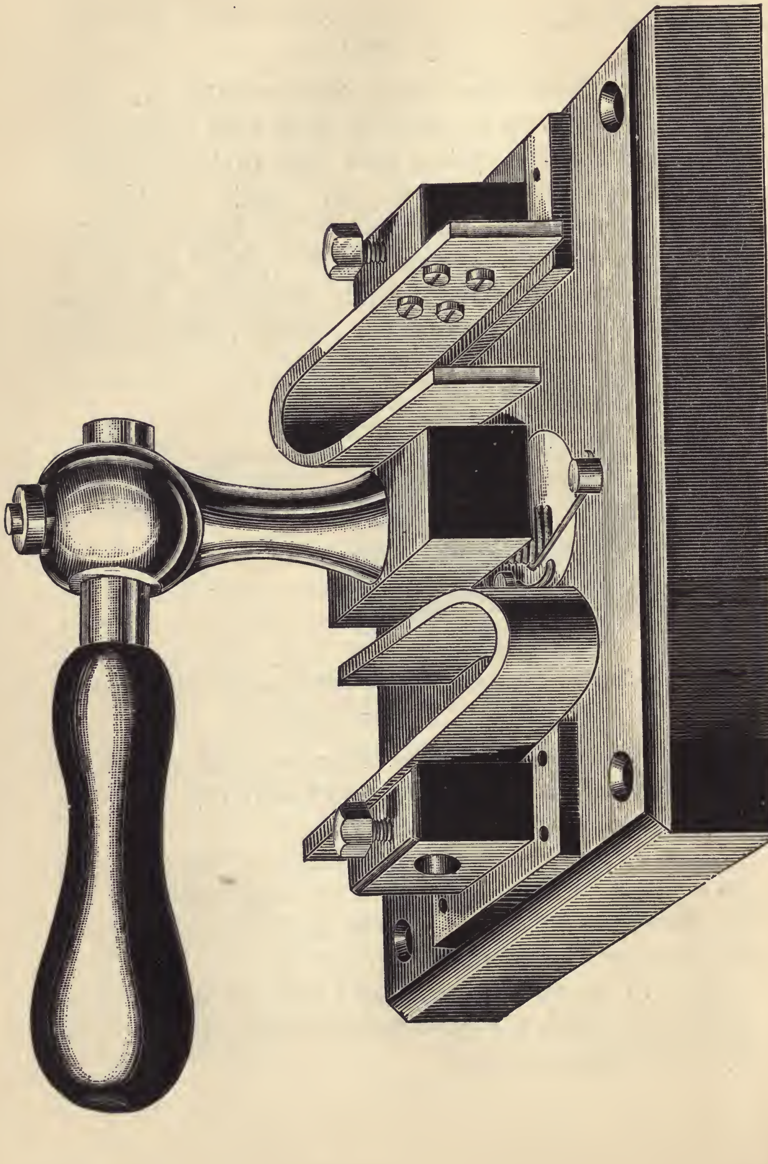


Fig. 72.—Author's Main Switch—Bent Spring Pattern.

Fig. 73 shows the English modification of the "chopper" switch.

Figs. 72 and 75 show the author's form of large switch.

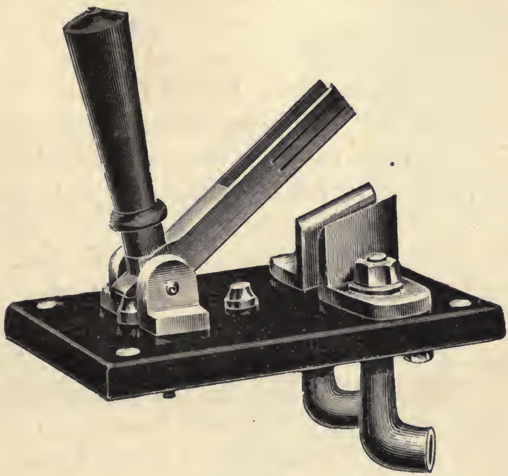


Fig. 73.

Double Pole Switches.

There are two forms of switch, however, which it will be of interest to describe, viz. what are called double pole switches and two-way switches.

The object of the double pole switch is to break the connection between both main cables, or in certain cases a pair of branch cables, and the dynamos, or the source of supply, at one operation. The object will be seen from the following:—It has been mentioned, in a previous chapter, that where two cables are used for supplying current to the lamps in different parts of the ship, if

one cable accidentally makes connection with the iron-work anywhere,—say by its insulation having been cut through on some sharp edge of metal,—should a connection to the ship occur on the other cable, or on any branch wire or cable in connection with it, the whole of the lights would be extinguished, and sparks would pass between either cable and the iron of the ship, should the connection between them be jerked loose again. It might happen that the first connection, between one cable and the iron of the ship would be right aft, while the second connection was forward; and it might also happen that while there was no time to look for the fault, it would be of great service to use the lights in one part of the ship, even if the others had to be laid off. For this purpose the double pole switch comes in, as one operation, turning one handle, breaks the connection of both mains; so that if there be separate circuits—say, for the lights aft, for those forward, and for the engine-room—any one of them can not only be cut off, so far as current for the lamps on that circuit is concerned, but also can be disconnected completely from the dynamo, so that they have no power to give trouble in the other circuits, as they might do if only one main was broken. It will be obvious that two switches, one on each main, will have the same result; and for ship work the writer prefers this plan. For shoregoing work, however, the insurance companies prefer the double pole switch, as their use makes it practically certain that when the main switch is turned off the wires in the building are, or ought to be, completely cut off from the supply. The writer's great objection to the double pole switch, as also to the double pole cut out, is that the full voltage of the

system is present at the switch, and that the full strain represented by that voltage is necessarily, from the con-

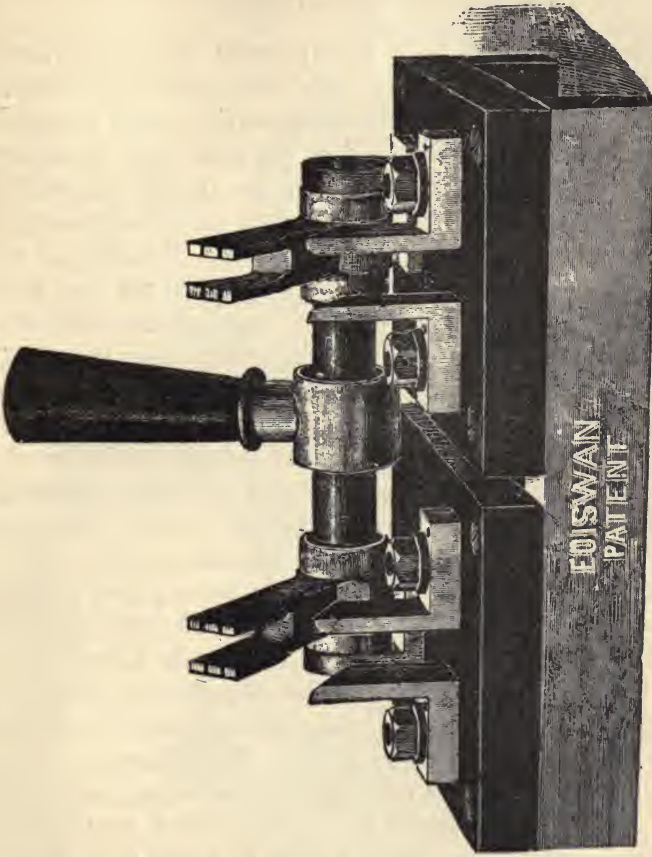


Fig. 74.—Double Pole Main Switch.

struction of the switch, brought to bear upon a piece of insulating material which is also subject to mechanical strain.

Fig. 74 shows a double pole switch made by the Edison Swan Co.

Two-Way Switches.

The two-way switch is a very useful one where there are two dynamos running. It is now pretty well acknowledged that, for safe continuous service, such as must rule in large passenger ships, at least two dynamos should be carried, either of which can furnish the whole of the lights, if required. With such an arrangement it becomes a question of how to use the dynamos, so as always to be sure that one will be ready for use, and that the wear and tear upon all the machines shall be at a minimum. In the writer's opinion the best and simplest plan is to have separate circuits for aft, forward, engine-room, and in some cases to divide the largest of these into two—that feeding the saloon for instance; and to connect each circuit at will to either dynamo, distributing the work evenly between them when all the lights are on, and throwing all the circuits on to one dynamo when only a few lights are required. This arrangement necessitates some simple and quick method of throwing any particular circuit, with its lamps, from one dynamo to another. Such an apparatus is provided by any well-designed and well-made two-way switch, a turn of the switch handle securing the desired transfer, with hardly a blink in the lamps that are being switched. The writer has designed the switch shown in Fig. 75 to accomplish this purpose, and a description of it, and of the connections, will probably make the thing clear; but, as already indicated, any well-made switch would do as well. The switch is designed on the same

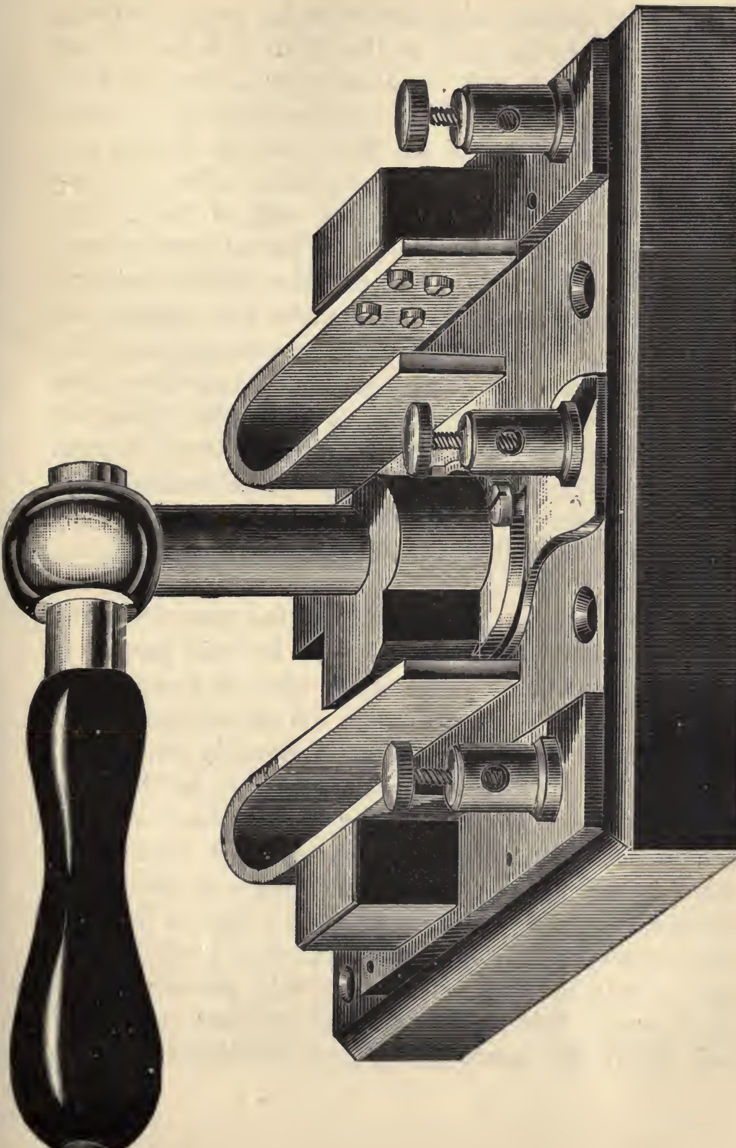


Fig. 75.—Author's Two-Way Main Switch—Bent Spring Type.

bent spring pattern that has already been described. The contact bar is made in the form of a bent lever, the two arms of which are at right angles to each other. By this means it is arranged that the contact bar only engages one of the fixed contact springs at a time, one of its arms being parallel with the two springs, while the other engages one of them. To reverse the switch, the handle is turned from left to right, or from right to left, as the case may be, quickly; the previously free arm of the contact bar engaging the free contact spring, while the other arm disengages. The contact bar, in this case, forms one connection, that to the lamps, while the springs form the connection respectively to the two diagrams. One terminal of both dynamos is always connected to one cable leading to the lamps, the other cable leading from the lamps being brought to the central contact bar of the switch, and through the latter to either dynamo, according to the way the switch handle is turned. One of the great difficulties with two-way switches that are used for this purpose is, to arrange the design so that there shall be no chance of a connection being made through the switch between the two dynamos. To avoid this the movable contact bar should be so constructed with reference to the fixed contact pieces, that it can never be in contact with the two at the same time. As will be seen by Fig. 75, there is no chance of this taking place in the switch designed by the writer, nor is it likely to occur in the majority of modern switches; but the writer had a switch sent to him some years back which was used temporarily while another was being made, in which it did occur, the result being that the direction of the

current given by one dynamo was reversed by the current from the other. This leads to the explanation of another plan which has been much advocated, and which is actually used in central station work on shore, but which the writer has always most strongly condemned, and the use of which he believes has led to considerable trouble and unnecessary expense. The plan alluded to is that of connecting all the leads from all the circuits together, and connecting the terminals of all the dynamos to them, the idea being that the latter will just pour their current into the former as into a reservoir, and the lamps will take what they want. The arrangement is founded upon the erroneous idea that the EMF, the voltage between the terminals of each dynamo is, and will always be the same; and it is supposed that if they are not so originally, the simple plan of connecting either the terminals or the brushes of the dynamos together, by means of a couple of pieces of copper wire, will make them so. In practice nothing of the kind takes place. Two dynamos may be made from the same iron, the same copper, and by the same hands, and yet will not turn out exactly alike. At the same speed one may be half a volt, or more or less, ahead of the other. When, therefore, the two dynamos are connected to the same supply mains, the one which develops the higher voltage will do all the work, the other being unable to deliver a current at all, until the voltage of the more powerful one comes down to its level. Further than this, the wires of the dynamo which develops the lower voltage form a path for a portion of the current delivered by the other, thus increasing the strain upon the latter. Connecting either terminals or

brushes together does not alter the EMF generated by either dynamo in the least, but it makes the delivery from one to the other more complete, and so adds to the trouble.

The writer has seen repeated instances of trouble arising from connections made in this way. One that is typical will explain the matter. Three high speed engines were connected directly to three dynamos, the latter furnishing lights at one of the exhibitions. The three dynamos were all connected directly to one pair of main-supply cables leading to the lamps. Things went all right for a time, when suddenly one engine stopped dead, a second one reversed, and the armature of the dynamo attached to the third burnt up. This was thought at the time to be "one of those things no fellow can understand"; but the explanation was very simple. The dynamo whose armature burnt up was the one furnishing the highest voltage, and doing all the work. Possibly up to the time of the breakdown the strain had not been very severe, as the difference was not great; but as these things tend to increase, the difference between the EMF's generated became larger and larger, till at last it was great enough to enable the one dynamo to drive its neighbour, with its engine, the wrong way, and to stop the third one — the enormous current developed in the process causing its own armature to burn up. In central stations they can, if they will, maintain the EMF of all the dynamos exactly at one figure; but it is very doubtful if they would not get a better result by dividing the work, letting each engine and dynamo do its own. For work on board ship at any rate, division is the thing, where more than one dynamo is used.

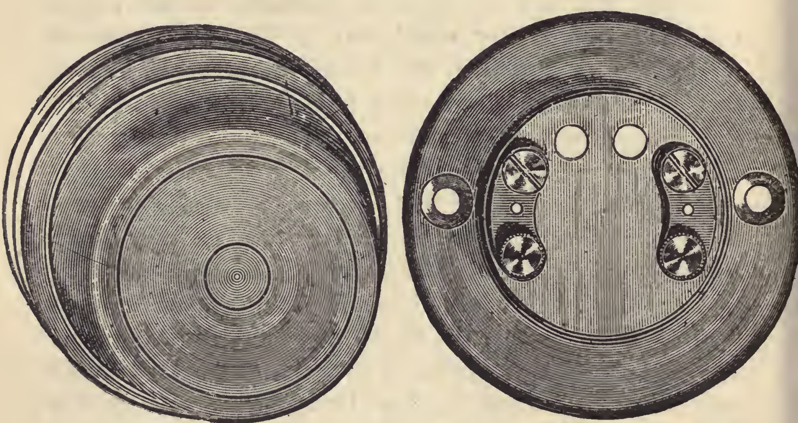
Cut Outs.

It has been already pointed out that when, by the sudden removal of the larger portion of the resistance of any branch circuit, or the sudden increase of the available EMF present, a powerful current is caused to pass through some of the small branch wires, the latter may become heated to such a temperature that not only will the insulation upon the heated wires themselves be destroyed, but any inflammable substance in the neighbourhood, such as dry wood, may be ignited. In order to provide against this, two forms of safety devices, or Cut Outs as they are termed, have been designed. In the cheaper and more common form, the Fusible Cut Out, either the lower melting point of certain metals is taken advantage of, or the current is made to pass through a short length of copper wire of very small section in proportion to the current it has to carry. A piece of lead wire or foil, or of small copper wire, is made to form part of the circuit to be protected, and the size of the fusible conductor is so proportioned that it will melt when the current passing through its circuit reaches a certain percentage above the usual working strength.

Alloys of lead with other metals, forming more readily fusible alloys, are also used for the same purpose.

For the convenience of replacing the "Fuse," as the piece of metal to be melted is called, after it has performed its office, metal frames are provided for them, mounted on wood, slate, porcelain, or other insulating material, just as switches are; and the fuses themselves are often made in the form of clips that will slip easily under the screw attachments provided for them.

Figs. 76 and 77 show the simplest form of fusible cut out, consisting of a circular slate, wood, or porcelain base, with cover of wood or porcelain, and two pieces of brass secured to the base by means of screws, leaving a second pair of screws free for the fuse wire to be connected to. Connection is made, as with the small switches, by turning the ends of the fuse wires and branch connecting wires round under each screw head, one on each plate, and screwing down.



Figs. 76 and 77.—Showing the simplest form of Circular Cut Out. Fig. 76 shows the complete apparatus and Fig. 77 the same with Cover removed.

Figs. 79 and 80 show a later and better form of fusible cut out, made only with porcelain base. The base in this case is made in a rectangular form with a sort of bridge raised in the centre. Through this bridge pass two holes which take the terminal screws, these being arranged so that the service wires leading to and from the fuse are connected to the screws on one side of the bridge, and the fuse wire itself on the other side.

Fig. 80 shows a fuse with one fuse wire only, intended to protect one cable or branch wire. Fig. 79 shows a fuse with two wires, or a "DOUBLE POLE FUSE" as it has been termed, intended to protect both cables or

Fig. 78.—Showing form of "Bridge" Cut Out, with Cover

branch wires; that is to say, the cables connected to both sides of the dynamo.

Fig. 78 shows the complete fuse of either form with its cover, the latter being held in place by a thumb nut

on top, as shown. Probably in use on board ship the cover would soon be dispensed with.

The object of using double pole cut outs is the same as with double pole switches, viz. to ensure that any

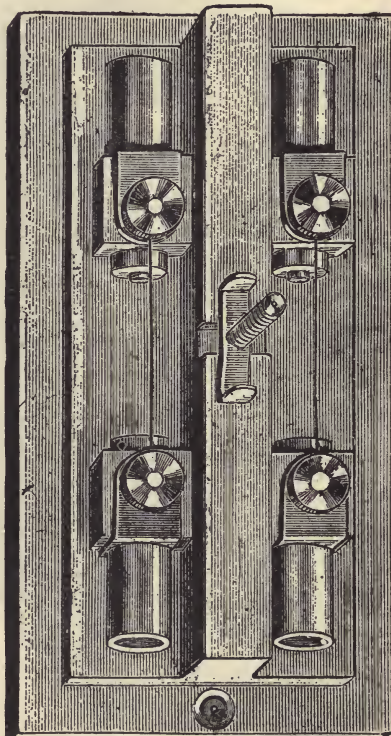


Fig. 79.—Showing form of "Bridge" Cut Out, with cover.

particular section of cable shall be cut off immediately a connection is formed that would cause it to heat dangerously, notwithstanding the fact that one side of the dynamo may be connected to the body of the

ship in quite another part from where the final connection and the dangerous heating takes place. To recapitulate, as the point is an important one. Suppose that a ship be fitted on the double wire system, and that a connection be made between a branch wire on one side of the dynamo and a beam, say in the forecastle. Later on, suppose that a connection is made on the other side of the dynamo, between one of the small wires leading to one of the lamps in the saloon and its metal holder, the latter being screwed to the iron deck above. The current will now pass from one terminal of the dynamo to the forecastle, will return by way of the body of the ship to the saloon, and from the lamp-holder in the latter to the dynamo by way of the wire which is touching its holder. The EMF furnished by the dynamo being undiminished, and being now opposed in this particular circuit by only the resistance of the cable and branches leading forward, those leading aft, the resistance of the contacts themselves and that of the body of the ship, a powerful current will pass, raising the temperature of the small wire which is touching its holder very considerably. If each branch be only protected by one fuse wire in one of its cables, it may happen that this cable is connected to the same side of the dynamo for the saloon circuit as the cable which has rubbed itself into contact in the forecastle, neither

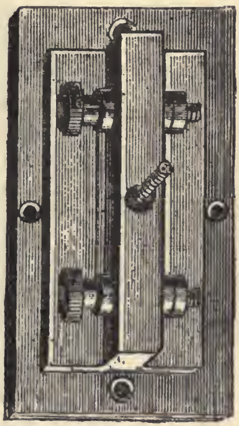


Fig. 80.—Showing form of "Bridge" Cut Out, without Cover.

of them containing the fuse, so that, as will be seen by the foregoing, there is no fuse in circuit in which the powerful current passes, and no protection is afforded.

Figs. 81 and 82 show forms of "CEILING ROSES," as they are termed—the apparatus that are used to make connection with a lamp when suspended from above. As will be noticed the arrangement of these ceiling roses is very

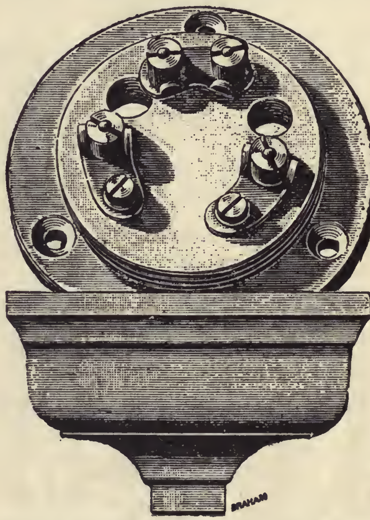


Fig. 81.—Showing Porcelain Ceiling Rose with Arrangements for Fusible Cut Out.

much the same as that of the cut outs, which have already been described, the only difference between them being that the ceiling roses have additional terminals for the extra wires, and a hole in the centre of the cover for the passage of the flexible cord conductor which supports the lamp.

As will be understood from the above, the ceiling rose performs the triple office of supporting the pendant

lamp, holding the screws by means of which connection is made between the supply wires—the branch wires leading from the dynamo—and the flexible wires leading to the lamp, and holding the wire fuse which is

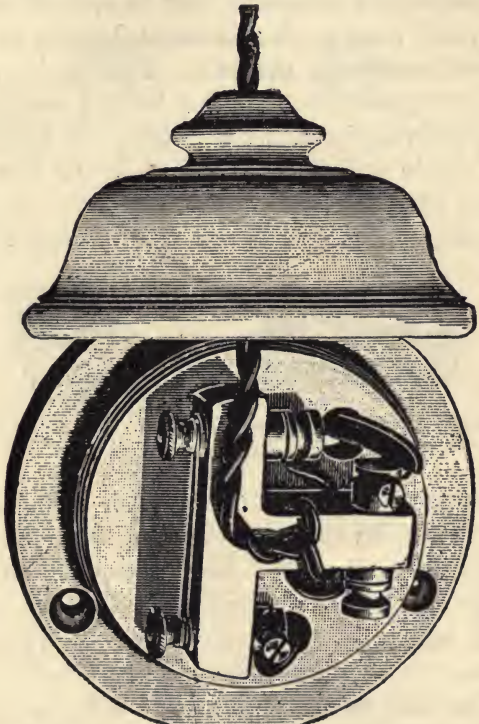


Fig. 82.—Showing another form of Porcelain Ceiling Rose with Fusible Cut Out.

intended to protect the small branch wires in case a connection is made at the lamp.

The arrangement of connections for that form of ceiling rose is shown in Fig. 82. For the form shown

in Fig. 81 the two supply branch wires may be connected to the two terminals on the right, one on each brass connecting piece on each side of the hole shown in the base, and the fuse wire may be connected to the two screws at the bottom of the base, as shown in the drawing, and the two flexible wires leading to the lamp to the two screws on the left. This is the most convenient arrangement, but any that forms a complete circuit with the dynamo, including the lamp, will answer.

The flexible cord referred to consists of two insulated strands of wire laid up together.

Each strand consists of a number of fine wires, their

Figs. 83 and 84.—Showing Edison's Fusible Cut Out, with the Screwed Plug in which he places his Fuse Wire.

gauge being usually No. 40, and their number depending on the current the lamp they are supplying requires, as 23, 40, 60, and so on. Each strand is covered with one or two layers of indiarubber. Flexible cords that are to be used in warm places should be insulated with vulcanised rubber, then with one or two layers of silk or cotton, the last usually being put on in the form of a braid, and being made as ornamental as possible.

Fig. 83 shows Mr. Edison's cut out, in which the fuse wire is held between two portions of a screw plug, as shown in Fig. 84. The object of this arrangement is that the fuse may be easily and quickly replaced after performing its office, spare screw plugs being kept handy.

It has the disadvantage for sea-going electric lighting plant, that it is more difficult to replace the fuse if you have no plugs in store, than with the other forms shown, as you can always find some piece of wire to fit the latter.

Fig. 85 shows another fuse, designed to effect the

Fig. 85.—Showing Fusible Wire with Clips for replacing readily in Fusible Cut Outs as Figs. 78 and 79.

same object, with other forms of cut outs; the jaws shown at each end of the fuse wire being intended to be clipped under the terminal screws, instead of bending the fuse wire itself for that purpose.

The following table, which is due to Mr. W. H. Preece, C.B., F.R.S., shows the current at which wires of different gauges and different metals will fuse:—

Current in Ampères.	Tin Wire. Approx. S.W.G.	Lead Wire. Approx. S.W.G.	Copper Wire. Approx. S.W.G.	Iron Wire. Approx. S.W.G.
1	36	35	47	40
2	31	30	43	36
3	28	27	41	33
4	26	25	39	31
5	25	23	38	29
10	21	20	33	24
20	17	17	28	20½
30	15	14	25	18½
40	13½	13	23	17
50	12½	11½	22	16
60	11	10	21	15
80	9½	8½	19	13½
100	8½	7	18	12
150	5½	4½	16½	10 small
200	3½	2	15	8
250	1½	0	13½	6½

The following table shows the fuse wires of various metals that will protect the cables of the sizes shown. The table is taken from Geipel and Kilgour's electrical tables:—

Dimensions of Conductors.	Fuse Wire. Lead.	Fuse Wire. Tin.	Fuse Wire. Copper.
20	24	26	40
18	22	24	36
16	20	21	32
14	18	19	30
$\frac{7}{22}$	18	19	30
$\frac{7}{20}$	16	17	28
$\frac{7}{18}$	14	15	24
$\frac{7}{16}$	11	12	22
$\frac{7}{14}$	9	10	20
$\frac{7}{12}$	7	8	18
$\frac{19}{22}$	14	15	24
$\frac{19}{20}$	12	13	22
$\frac{19}{18}$	9	10	20
$\frac{19}{16}$	7	8	18
$\frac{19}{14}$	5	6	16
$\frac{19}{14}$	2	3	14

Of the other form of cut out which has been mentioned, that designed to break the circuit which it is to protect, by the aid of an electro-magnet operated by the current itself that is to be controlled, one type is shown in Fig. 86. The ends of a stout wire, bent as shown, dip into two metal cups that are filled with mercury when the apparatus is in use.

The terminals of the apparatus, which are shown in the lower part of the drawing are connected by means of brass bands, one to the inner mercury cup and the other to the end of the wire coils of the electro-magnet which works the apparatus. The outer mercury cup

being also connected to the other end of the coils of the electro-magnet, the current, in passing through the cut out, enters at one terminal, passes through the wire coils before referred to, thence to the outer mercury cup, and thence by way of the stout bent copper wire shown to the inner cup, and so to the other terminal. To the stout bent copper wire is attached a tumbling armature, which

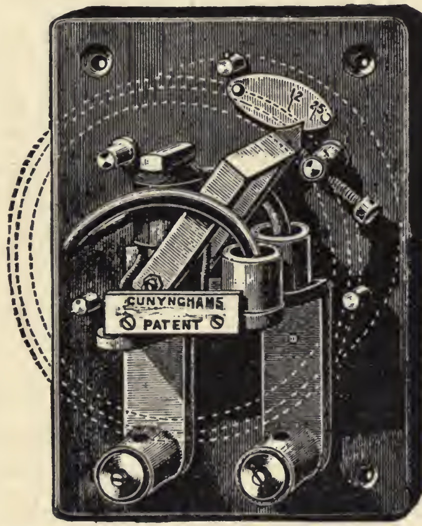


Fig. 86.—Showing Cunyngham's Electro-Magnetic Cut Out.

is pivoted below, and carries a finger working over a gauge above. By means of the set screw shown at the right of the drawing the armature can be placed nearer to or farther from the poles of the electro-magnet, the object being to cause it to break circuit when a larger or smaller current passes through the apparatus.

The farther from the poles the armature is placed the

larger will be the current required to break the circuit, and *vice versâ*, as will be seen on the scale. When this current passes, whatever it may be, the armature is attracted by the poles of the electro-magnet with sufficient force to cause it to move in that direction.

As the armature moves towards the poles of the electro-magnet the ends of the bent wire attached to it rise out of the mercury cups, and the circuit is broken. The bent wire would now fall back into the mercury cups, and there would be a succession of makes and breaks, but for the ingenious operation of the tumbling armature. The latter, instead of returning to the position from which it rose in obedience to the pull of the current, falls back on the other side behind the electro-magnet, so that the circuit remains broken until the tumbling armature is moved over by hand, and the ends of the bent wire are replaced in the mercury cups, an operation that takes only a few seconds to perform.

This apparatus is made either to be placed in the main circuit or any branch circuit, to operate by an excess of the total current passing in the circuit it is intended to protect; or to be placed in a shunt or loop circuit with the dynamo or any part of branch cables, and to operate whenever an excess EMF is present at that point.

Fig. 87 shows another form of electro-magnetic cut out designed by the author, which he has used with great success in many situations on shore, and which he has made in various sizes up to 400 ampères.

The apparatus consists of a tumbling contact lever, having a balance weight for one arm, and one or more

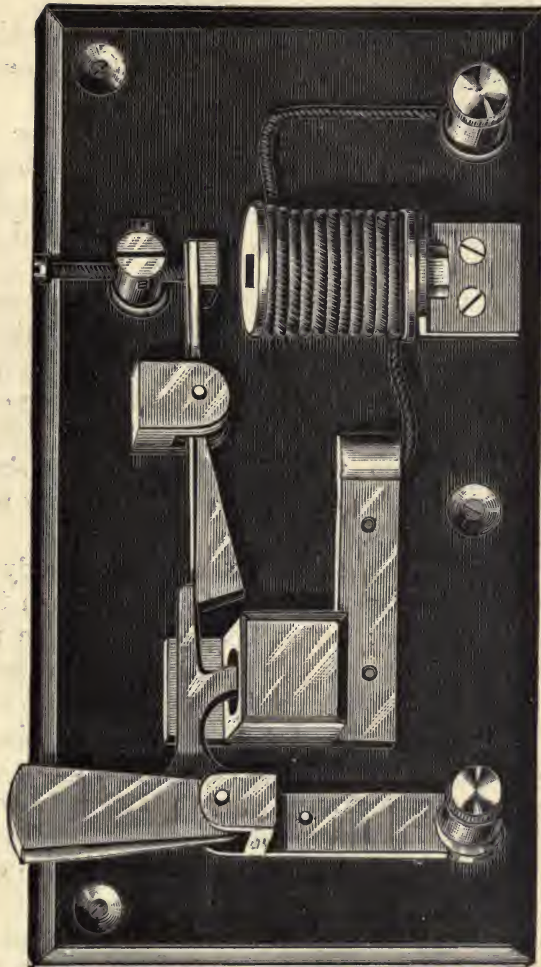


Fig. 87.—Showing the Author's form of Electro-magnetic Cut Out.

contact pieces, made in the form of claws, attached to the other arm.

The contact pieces dip into mercury cups, which also form part of the circuit the apparatus is intended to protect.

Engaging with the end or toe piece of the contact lever is one arm of a second lever, whose other arm carries an iron armature, arranged to face the pole of an electro-magnet, whose coils are also included in the circuit to be controlled.

On the arrival of the current for which the apparatus is set, the armature is pulled quickly down to the pole of the electro-magnet, the other end of the armature lever jerking the contact lever back, the latter falling over and thus breaking the circuit.

For board ship work the mercury cups should be specially constructed, so that the mercury may not spill when the ship rolls.

The electro-magnetic cut out must be properly proportioned to the current that is to pass through it, under normal conditions; but each apparatus can be made to operate at any percentage, above the normal current, that may be desired; thus an apparatus intended to control a circuit in which a current of 50 ampères is passing, would be made to operate at about 70 ampères, but it could be arranged to operate at any figure, say, 100 or 150 ampères.

The author has also recently arranged a modification of this apparatus, to break the connection of both cables at the same moment.

The principle of another type of electro-magnetic cut out that has been somewhat used is the same, but only one break is usually employed, and mercury cups are

dispensed with, rubbing spring contacts being used in place of the ends of conductors dipping into the mercury.

In this form of apparatus the circuit is broken by means of a gap between two stout metal springs, which are connected together, when the current is passing, by a movable contact piece.

This contact piece may be either attached to the armature of an electro-magnet, which, when the current reaches a certain predetermined strength, has sufficient force to pull it clear of the springs, in spite of the friction between them, and so break the circuit; or the movable contact piece may be attached to one arm of a trip lever, which is released by the pull of the electro-magnet upon its armature, when the current reaches a certain figure.

The trip lever arrangement, a device very often used in electrical apparatus, is the best, as it allows a powerful spring to be brought into operation, so as to quickly pull the movable contact piece clear of sparking distance, and avoid the burning of the spark, just as in the switches that have been described.

So far as the writer's experience has gone, the mercury contact cut out is the best, as the contacts necessarily keep themselves clean, but it has the disadvantage of using the fluid mercury, which is liable to slop over in heavy weather, and which is not a nice substance to handle.

On the other hand, it appears to be a difficult matter to design a good substantial form of spring cut out, that will maintain its contact surfaces in the form they should be if it has much work.

It should be noted, however, that in the early days of

telegraph work, mercury contacts were very frequently employed, and for the same reasons as they are now employed in cut outs, but have been long since abandoned. As between electro-magnetic cut outs and fusible cut outs, the writer prefers the former, because they are more certain.

Though the scale that is attached to the electro-magnetic apparatus may not be accurate, it is not difficult to set the apparatus to break circuit at any desired excessive current. With fuse wire cut outs, however, there is always a large amount of uncertainty. The vibration of the main engines, the rolling of the ship, and even the passage of the current itself through the fuses, tend to strain them and to render them brittle, so that they often "go" when no excessive current is passing, unless they are set very much above what ought to be the actual requirements; in which case they do not protect so well during the early period of their life.

There is also another element of uncertainty about fusible cut outs, viz. the difference of the cooling effect of the surroundings under different conditions.

Thus, in a very cold atmosphere, a fuse wire will not melt so readily as in a very warm one. Also, if the quantity of metal in the fuse terminals is large, and more particularly if these terminals are exposed to cooling influences, such as draughts of air, the melting of the fuse wire will be very much retarded, and its protective influence proportionately decreased.

Some years ago the author purchased some fuses in London, which were designed to melt with from 1 to 1½ ampères. On testing them at his works a current of

45 ampères was passed through them, and it was only with difficulty that they were even then melted, though the fuse wires were not large. The reasons were those given above,—the cooling effect of the terminals, and of the position. The heat generated in the fuse wire was passed by heat conduction to the brass blocks forming the terminals for the fuse, and from them to the atmosphere, so that it was only when a powerful current was passing that heat was generated at a sufficiently greater rate than it was carried off, to raise the wire to the required temperature within any reasonable time. The wire fuses made at the present day are considerably better than were to be had in those days, and they are therefore now more reliable; but the same reasoning still holds good to a large extent.

Another point that should be mentioned with wire fuses is, the fact that on the melting of the fuse wire small globules of molten metal are scattered around, and there should not be any inflammable material near enough to be set on fire. Where the fuses are retained under porcelain, metal, or hard wood covers, there is no danger of this.

For large currents it is best, if fusible cut outs are employed, to divide the fuse wire into two, three, or more wires or foils of different lengths. The longest wire will usually melt first, where the conditions are the same, both on account of the greater quantity of heat generated in a given time, owing to the increased resistance, and also on account of the greater proportion of metal in the fuse wire to that in the terminal blocks, within certain limits.

Where mercury contact cut outs are used, small

quantities of the mercury will be vaporised by the spark each time the cut out operates, and will be generally deposited on some part of the apparatus later on. This would also dictate division of the cut out where large currents are used, so as to divide the spark up as much as possible.

Switch Boards.

It is now usual to collect the main switches, fuses, cuts outs, and measuring instruments together at a convenient position, usually near the dynamo.

A pair of cables are brought from the terminals of the dynamo to a pair of terminals on the switch board, as the board on which this collection of apparatus is called, and branch cables are led from their respective switches on the switch board to the different parts of the ship they are to supply.

It is also now frequently the practice to have sub-switch boards in convenient positions, on which may be mounted a controlling switch for the whole of the lamps supplied by that board, and also smaller switches and cut outs, more frequently only cut outs, controlling the smaller branches that emanate from the board.

The use of sub-switch boards, or fuse boards, as they are sometimes termed, has the advantages that fewer joints are required, and the whole thing is under much more complete control.

The cut outs for any group of lamps being all at one spot also, very much facilitates the replacement of fuses when burnt out.

Main switch boards and sub-switch boards should be of enamelled slate, and, where possible, the connections

between the different pieces of apparatus should all be in sight.

The main switch board should carry one voltmeter for each dynamo, and one ampère meter either for each branch circuit, or for two or three together.

Ampère and voltmeters are described in the next chapter.

CHAPTER VI.

MEASURING INSTRUMENTS.

All the instruments that will be described, those that are of interest to marine engineers who have to deal with electric light apparatus, are based upon the fact mentioned in Chapter I., that an electric current possesses and exerts all the properties we are familiar with, as belonging to the natural magnet, viz. the ability to attract iron which is not magnetic, and to cause a magnetised needle to move in a particular direction.

Instruments of this kind may be broadly divided into two classes. Those which merely indicate the presence of an electric current, and those which measure its actual strength in ampères, or the EMF in volts. Other instruments, to measure the resistance of any circuit, or portion of a circuit, and to measure the energy used in any circuit, have also been designed, and are used by electrical engineers, but marine engineers need not trouble themselves with them.

The only example of the first class of measuring instrument that will be described here is an old instrument much used by telegraph men, which has been called, from that fact, the Lineman's Detector. No railway or post-office lineman, with several miles of wire under his charge, would ever go out without one. The lineman's

detector consists simply of a compass needle with a few coils of insulated wire round it. It is shown in Fig. 88. In these detector galvanometers, as they are also called, a magnetic needle is suspended in a vertical plane, inside a framework on which are coiled a number of turns of silk-covered copper wire, the ends being brought out to terminals, for convenience in directing a current through them. The coils are also vertical, and the current when passing through them deflects the needle magnet inside them out of its original position, in obedience to the law already stated on page 15, viz. if you are looking at the back of the instrument, and the current passes up in front of you and down the opposite side of the needle, the N. pole will turn to your left hand, the S. pole to your right. It is obvious that, as each turn up and down produces its own effect upon the needle, the greater the number of coils on the instrument the greater will be the deflection of the needle, with a given current. It will also be understood from what has gone before, that the effect upon the needle will be in proportion to the strength of the current passing, and to the number of coils through which it passes, and this law is taken advantage of for the purpose of arranging, in one handy portable instrument, for accomplishing two widely different tests. The DETECTOR GALVANOMETER is usually wound, first with a few coils of comparatively thick wire, and then with a very large number of coils, as many as the frame will hold, of very fine wire, each coil of course being insulated from its neighbour.

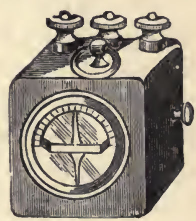


Fig. 88.—Showing a Lineman's Detector Galvanometer.

The axis upon which the needle magnet is suspended, also carries a pointer needle, which moves over a graduated dial, and thereby indicates the number of degrees to which the magnetic needle itself is deflected. The deflection forms a rough guide as to the strength of the current passing in the coils, and is useful for comparison. This instrument, which is of great service in detecting faults, will be further alluded to in the chapter dealing with that portion of the subject.

It will be sufficient here to state that the thick wire coils are used to detect the presence of a current moving under the pressure of a low EMF, usually a comparatively strong current, and the thin wire coils are used to detect the presence of a very small current, such as would pass through imperfectly insulating material in obedience to the pressure of a comparatively high EMF.

The effect of the comparatively strong current passing round the needle only a few times, and of the very weak current passing round it a good many times, being the same, when the product of the current strength × by the number of turns is the same.

The other class of instruments, named respectively Ampère Meters, or Ammeters, and Voltmeters, are constructed on various patterns, but all on the same leading principles. Either a small needle magnet, held in the centre of the magnetic field created by a powerful horseshoe magnet, is caused to turn on its axis, in opposition to the pull of the magnet; or a piece of iron of a certain shape, varying with different inventors, is caused to alter its position relatively to certain coils of wire, in which the current passes. In more than one inventor's instruments, the current passing in the coils of wire on the

instrument is caused to pull down a piece of iron into the centre of the coils, and by means of multiplying gear of various forms to move a long pointer needle over a graduated scale. Figs. 89 to 96 show the construction of various forms of these apparatus. Figs. 89 and 90

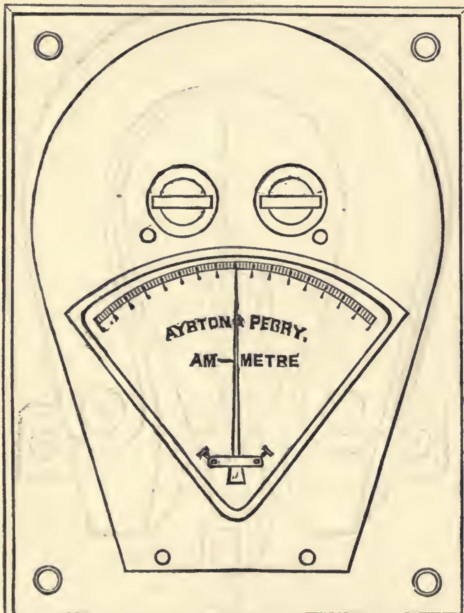


Fig. 89.—Showing the Outside of one of Ayrton & Perry's Ampère or Voltmeters.

show the earliest form of measuring instrument that was introduced in this country, the invention of Professors Ayrton & Perry. In it, the first idea that was mentioned is made use of. The Horse-shoe Shaped Permanent Magnet, with its specially shaped soft iron pole pieces,

creates around the needle magnet, suspended between the latter, a powerful magnetic field, which is able at all times, and in all positions of the instrument, to overcome the effect of the earth's magnetism. The shape of the pole pieces and the arrangement of the coils is also

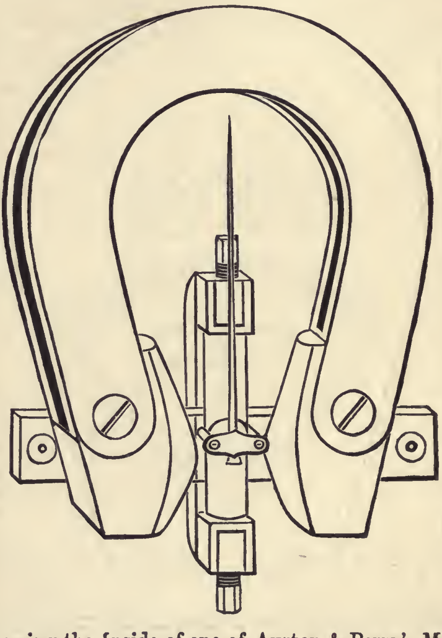


Fig. 90.—Showing the Inside of one of Ayrton & Perry's Magnet Ampère or Voltmeters.

designed that the action of the current upon the needle may be the same in all positions of the needle up to the limits of the scale, which extends to 45° on either side of zero. By this arrangement, each degree of deflection corresponds to a certain definite measurement in ampères

or volts, as the case may be, and it is only necessary to multiply the number of degrees by this constant, as it is termed, to obtain the measurement desired. Thus some ampère meters of this type were made to give 1° deflection for each ampère of current passing through them. Others gave one degree for each 1·5 ampère, 2 ampères, and so on. Others again gave 10° for each ampère, so that 1° represented one-tenth of an ampère. Similarly some voltmeters gave 10° deflection when an EMF of 1 volt was present; others gave 1° with 1 volt, 1° with 5 volts, and so on. The ampère meters reading 10° for one ampère were and are used to measure the current passing through individual incandescent lamps.

Some of these low reading instruments were arranged also, so that by turning a barrel forming a commutator, or apparatus to alter the direction of the current passing through the instrument, they could be used to measure currents varying in strength as 1 to 10, and by the addition of a coil of wire to the instrument, that could be connected or not at will, the accuracy of the readings could be tested.

The permanent horse-shoe magnet class of instruments, however, and especially those fitted with commutators, have passed out of general use, in favour of instruments which denote the current strength or voltage present, in the actual figures, without the necessity of multiplication by a constant. Apart from the fact of this matter of multiplication being troublesome at times, the horse-shoe magnets tended gradually to lose their power, as all steel magnets do, this of course decreasing the value of the readings, as now a weaker current would do the same

work, there being less opposition from the permanent magnet, that a stronger current did before. Thus an instrument reading, when new, 1° for each ampère of current passing, after being in use some time, might only require ·9 or ·8 ampère to produce a deflection of 1°.

The above is what theory said, and it was perfectly correct; but the theory failed to take into account another important factor which, in the author's experience, tended to reverse the operation, making the readings less than they should have been. This factor was the increase of friction upon the pivots upon which the needle magnet was suspended. Dirt, dust, and rust invariably crept in after the apparatus had been in use a little while, and at such a rate as not only to neutralise the decreased strength of the magnetic field, but to render an increased current strength necessary to give a certain deflection. Another cause also tended to decrease the use of these instruments, viz. the effect of the heat produced in them by the passage of the current through their coils within the confined space allotted to the latter, which sometimes produced disconnections inside the apparatus. To those who were engaged on electric lighting work fifteen years ago, however, the advent of these instruments was a great boon, and they have done great service.

The next class of instruments to come on the market, also the invention of Messrs. Ayrton & Perry, are shown in Fig. 91. In these the principle of what is known as the SUCKING MAGNET is adopted. A coil of wire, in which a current is passing, having no iron core in its centre, will draw an iron rod or cylinder, placed for the

purpose, into the cylindrical space that would be occupied by the iron core, if one had been used.

In these instruments the iron rod which is sucked into the coils of the instrument is attached above to a

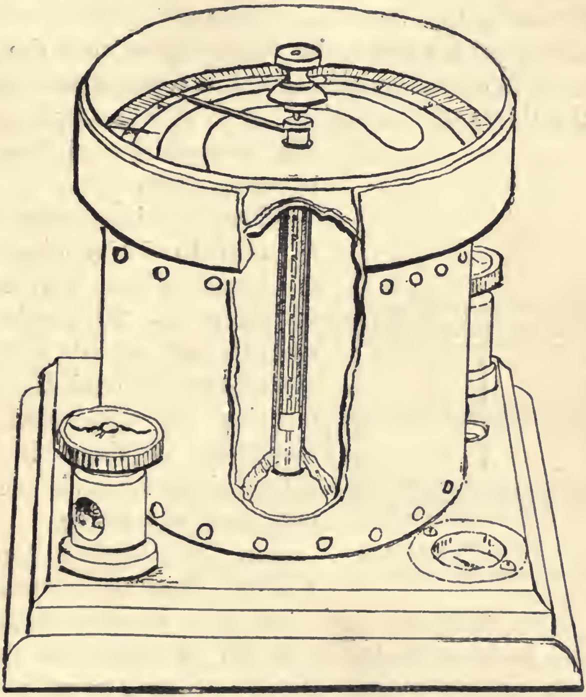


Fig. 91.—Showing the Inside and Outside of one of Ayrton & Perry's Helical Spring Ampères or Voltmeters.

helical spring, as shown in Fig. 91, the other end of the spring being attached to the pointer needle that moves over the dial. As the spring distends, its free end, with the pointer attached, moves round the dial,

indicating by its position the strength of the current passing, or the number of volts, which are read off in actual figures at once.

In these instruments, however, and in nearly all those which have followed, the spaces on the dial corresponding to different increments of current strength or voltage are not equal, the reason being that the pull of the coils upon the iron core is not the same throughout the limits of its motion, being at first small, gradually increasing, and then decreasing again.

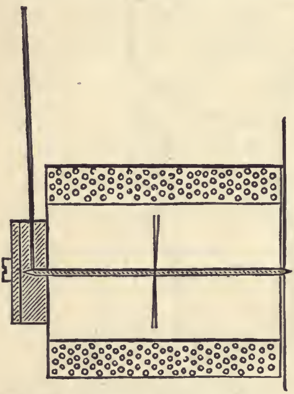


Fig. 92.—Inside View of Instruments mentioned below.

Thus, in an instrument made to read to 50 ampères, the arc over which the needle travels up to 20 ampères is usually so small that no measurements could be taken differing by less than 10 ampères. Between 20 and 30 ampères the scale spreads out more and so on.

Fig. 92 shows a type of a large class of instruments that have been and are being made, in which a needle magnet is pivoted inside a coil of wire, the needle forming, directly or indirectly, the short arm of a light lever, usually bent, the long arm being the pointer. In some of these instruments the readings are all equal, but generally they follow the same rule as that mentioned for Ayrton & Perry's helical spring instruments, viz. small spaces on the dial for low readings, then larger spaces, and then smaller spaces again. In choosing these

instruments for particular work, those having large spaces at that portion of the scale that is most used are best. Thus, with the ordinary ship installation, working at 60 to 65 volts, the voltmeter would be chosen that has large spaces on the dial between, say 55 volts and 70 volts; and if the current generally employed is about 50 ampères—corresponding to fifty lamps of 16 candle-power—the ampère meter reading large between 40 and

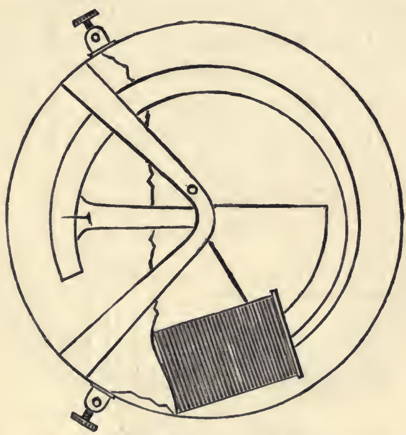


Fig. 93 —Showing Inside of Bürgin's Ampère and Voltmeter.

60 ampères would be best. Fig. 93 shows an instrument, designed by M. Bürgin of Bäsle, in which the coil of wire is made without a core, and the latter, which is of a sort of crescent shape, is gradually pulled through the coil as the current strength increases, in opposition to a spring placed for the purpose.

In Fig. 94 is shown the details of another class of measuring instruments that was first introduced by Herr Schuckert of Nurnberg

The coils are of a circular form, and a piece of bent iron is suspended within the space in the centre of the coils, but slightly out of the actual centre.

To the same pivot is attached the usual long needle pointer, which sweeps over the dial.

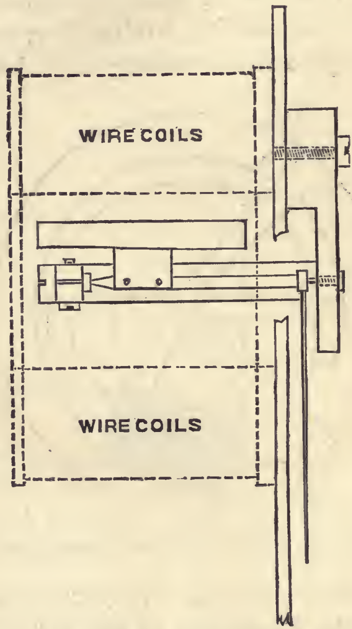


Fig. 94.—Inside View of Apparatus mentioned on p. 217.

When current passes through the wire coils, the movable piece of iron within them turns towards the point where the magnetism is strongest, or, as electricians express it, where the lines of force are densest, carrying the pointer needle with it over the face of the dial, and registering either the EMF or the current strength.

In these instruments, the spaces on the dial are unequal, the instruments being arranged so that the largest readings are where most required, as already explained.

In a modification of this instrument, however, made by

Fig. 95.—Showing Edison-Swan Ampère Meter.

the Walsall Electrical Company, a small core of iron wires is fixed within the central space, the moving piece of iron resting against it when no current is passing, and being repelled from it more and more as the current strength passing in the coils increases. The addition of this iron

core has the effect of making the readings equal within the limits of the instrument.

Fig. 95 shows an outside view of an ampère meter made by the Edison-Swan Co.

In all of these instruments the only difference between those intended to indicate the EMF, and those intended to denote the current strength, is in the gauge of wire with which the coils are wound. With ampère meters the whole strength of the current to be measured passes through the coils, and these must be made of sufficient size, therefore, to allow of its passage without undue heating. As also the current passing is large, only a few turns round the needle or other working part of the apparatus are needed to produce the required deflection. The number of turns, of course, in all current-measuring apparatus will be inversely as the strength of the current to be measured, the product of the number of ampères × the number of turns being approximately the same in all instruments of a certain type within certain limits.

With very large currents, often the conductor through which the current passes consists merely of a band of copper.

In voltmeters the gauge of the wire on the coils is always small, the gauge diminishing in direct proportion to the increase of the EMF to be measured. Thus, with a voltmeter designed to measure up to 100 volts, the gauge of the wire will be about four times that used in an instrument of the same size and type designed to measure up to 400 volts.

In measuring the EMF present at the terminals of a dynamo, the terminals of a lamp, between two cables, or

between one cable and the body of the ship, the voltmeter coils are bridged across just as a lamp is.

As the resistance offered by the wire coils remains constant so long as their temperature is not raised, and as, of course, the number of coils in any particular instrument is constant, the measure of any EMF applied to the instrument is the current which it is able to force through the wire coils, in opposition to their resistance; and the effect of this current is denoted by the deflection of the needle, or whatever the arrangement may be which the current moves. Many of the voltmeters at present in the market, however, that are constructed with wire coils, acting electro-magnetically as described, should not be allowed to remain connected to any circuit for more than a few minutes at a time.

The reason is, that these instruments are constructed of such a size that the gauge of the wire corresponding to any voltage that is desired to be measured is not sufficient to prevent an increase of temperature, if the measuring current is passing through for more than a few seconds at a time. This increase of temperature, though it is imperceptible externally, increases the resistance of the coils themselves, thereby decreasing the current passing through them with any given voltage, and so reducing the readings given by the instrument. If, in making tests with a voltmeter, the readings are suddenly reduced without apparent cause, lay the instrument aside for a time, and when next taken for testing it will usually be found to give the same indications as before. If a voltmeter is very much heated once or twice, however, the readings may not come back to their

old figure, and it is therefore wise to be careful not to allow such a thing to happen.

It is a good plan for those in charge of electric light apparatus to familiarise themselves with the appearance presented by the lamp filaments, when certain voltages are present at their terminals, and when the filaments have burned a certain time, as such indications afford a valuable check upon the readings of the voltmeter.

Thus the filament of a 16 candle-power lamp, when new and working at its proper voltage, is a bright yellow in colour, just turning to white. When over-driven it becomes white, and gradually acquires a dazzling brilliancy up to the point of destruction.

Below its proper voltage, when new, the filament gradually passes through the usual changes of yellow, dull yellow, bright and dull red, and black.

As the life of the filament increases, its resistance also increases, from the fact that carbon commences to be taken from its body and desposited on the inner surface of the glass.

The increased resistance means decreased current with a given voltage, and therefore less light, as before explained; the reduction of the current strength having a greater effect on the heat and light generated than the increased resistance.

In any particular installation, however, and, in fact, with any particular type of lamp, it is not difficult, with practice, to judge when a lamp is giving its proper light under the conditions, and so to judge whether the voltmeter is reading right or not.

Instruments are now made that will not heat when left permanently in circuit. The plan adopted with the

older instruments is to place a push or circuit-breaker, in the voltmeter circuit, in such a position that it can easily be reached by the hand. The push or key is pressed each time a reading is taken.

A very beautiful instrument, of which many have been used on shore, has been designed by Colonel Cardew, one of the advisers of the Board of Trade.

One form of the instrument is shown in Fig. 96. It is constructed upon the principle that any metal expands when heated, and that the expansion can be caused to move a needle over the face of a dial.

In the Cardew instrument, which has only been made to measure electro-motive forces, up to the present, a thin wire of platinoid, an alloy of platinum, is stretched over small rollers, inside a long tube. The wire passes up and down the tube twice; that is to say, the length of wire used is about four times the length of the tube in which it is stretched.

In some forms of the instrument the tube is arranged to stand vertical, in others horizontal. In both forms a circular metal case is placed at one end of the tube, a dial with a light needle pointer sweeping over its face occupying the front of the case.

Centrally in the cylindrical case is fixed a spindle, on which the pointer needle is pivoted, and the elongation of the fine platinoid wire within the tube is caused to rotate the spindle within the cylindrical box, and with it the needle pointer, the latter moving over the dial face.

The elongation of the wire is communicated to the spindle in various ways. One method is by attaching a piece of silk thread to the bight of the wire, passing the silk thread round the spindle, and keeping it in

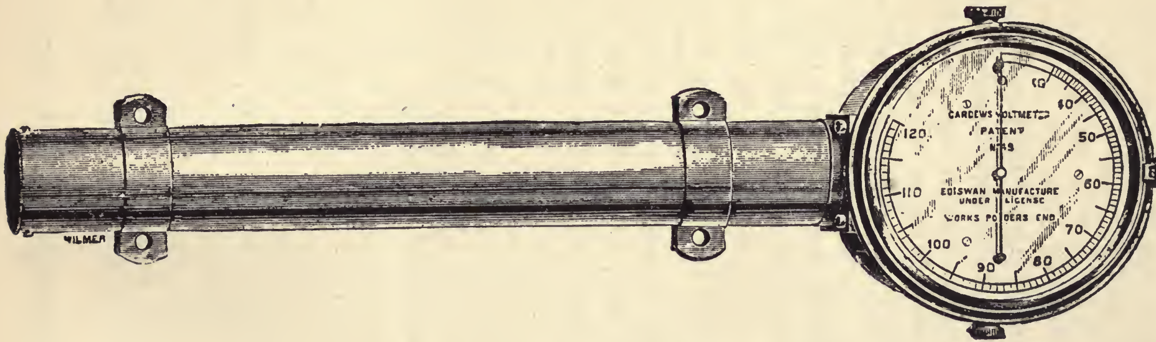


Fig. 96.—Showing Cardew's Hot Wire Voltmeter.

tension by means of a small spiral spring attached to its other end.

When the wire is at its normal temperature, that of the surrounding atmosphere, the spring is unable to turn the spindle, and so the pointer needle stands at zero. As the wire elongates, the pull of the spring upon the silk turns the spindle and the needle, the angular distance moved over by the needle measuring the total elongation of the wire, which again is proportional to the electro-motive force present.

The two ends of the platinoid wire are connected to terminals, on the outside of the cylindrical case in which the needle moves, wires from the terminals of the dynamo, or the cables between which the electro-motive force is to be measured, being connected to the same terminals.

The instrument works in virtue of Ohm's law and Joule's law.

When connection is made between the terminals of the instrument and those of the dynamo whose electro-motive force is to be measured, a certain current passes through the wire in obedience to Ohm's law, viz.

$$C = \frac{E}{R}.$$

This current heats the wire in virtue of Joule's law, viz. $H = C_2Rt$.

Or, if it be preferred, Ohm's law can be left out of account altogether, only Joule's law being noticed, but in its other form, viz. $H = \frac{E^2}{R}t$.

Whichever formula is used, it must be remembered

that, as the temperature of the wire rises, so does its resistance, so that the final current passing, and therefore the final temperature attained by the wire, is less than would have ruled if the wire had not altered its physical condition.

For this reason the spaces on the dial representing various electro-motive forces are very unequal. They necessarily become proportionately larger as the electromotive force is higher.

The tube in which the heated wire is enclosed is made of two metals, much as compound pendulums are, in order that the expansion of the tube, under the influence of the heat generated in the wire, shall not alter the conditions, by lengthening the base upon which the wire is stretched.

In the first edition of this book the author expressed the opinion that this instrument, beautiful as it undoubtedly is, was unsuited for "board ship" work.

A critic in an electrical paper, with the usual omniscience of critics, objected to this statement, and expressed the opinion, somewhat forcibly, that if there was one place the Cardew voltmeter was especially adapted for, it was on board ship.

Probably this critic

> "Never had been to sea,
> And a storm he never had seen."

As the author has seen a good many storms he sticks to his guns. If any reader has a Cardew instrument in use the author will be glad to hear from him.

It may not be amiss to conclude this chapter by explaining how the horse-power required in the engine

driving the dynamo for any given number of lamps is arrived at.

Each lamp of 16 candle-power, when new and furnishing its proper light, requires an expenditure of 60 watts.[1] The watt, it will be remembered, is the unit of energy, and is the energy expended when a current of 1 ampère moves between two points, in obedience to a pressure of 1 volt. Sixty watts, therefore, may be the energy expended in a lamp whose filament has a current of 1 ampère passing through it, with a pressure of 60 volts at its terminals. Seven hundred and forty-six watts, as already explained, equal 1 horse-power, 33,000 foot-pounds.

Take, therefore, the number of 16 candle-power lamps, and multiply this figure by 60, which will give the total energy expended in the lamps. If there are any lamps of higher candle-power, such as 25 candle-power, 32 candle-power, 50 candle-power, and so on, the energy expended will be in the same proportion; thus for 32 candle-power, 120 watts are required; for 50 candle-power, 187½ watts. For some of the larger forms of incandescent lamps, from 150 candle-power upwards, the energy expended per candle-power is rather less, a 200 candle-power lamp requiring only from 500 watts.[2] To the energy expended in the lamps should be added that expended in the cables; but in all but very large ships this would be small. In fact, this item is usually neglected, as the energy expended in the cables is really taken from that designed for the lamps, the latter being

[1] This quantity will be reduced as the manufacture of the lamps improves.

[2] High candle-power lamps are made either to work with small current, or to have long life, as preferred.

run a trifle under power in nearly every case. In many cases on shore, however, the expenditure of energy in the cables is considerable.

To the energy expended in lamps and cables, must be added that expended in magnetising the coils of the field-magnets and armature of the dynamo, in wasted currents in the iron cores, and sparking at the commutator. These, together with the friction of the revolving spindle in its bearings, and the friction of the air churned up by the revolving armature, amount to from 10 % to 20 % of the energy given out by the dynamo when at full load. Thus, supposing the dynamo to furnish 100 ampères at 60 volts, the equivalent of 100 16 candle-power lamps, equal to 6000 watts, the energy expended in the dynamo itself may be taken at from 600 to 1200 watts. Take the latter figure for safety, and we have a total of 7200 watts, or $\frac{7200}{746}$ horse-power, or about $9\frac{1}{2}$ horse-power, as the energy required to be delivered at the spindle of the dynamo. To this must be added the energy expended in the belt where one is used and in moving the working parts of the engine itself, usually in the small engines used for electric lighting work about 15 %, making a total horse-power in the steam cylinder of the engine of about 11 horse-power.

It should be mentioned that, when the dynamo is not working at full load, a large portion of the charge for generating the current is still made, so that the horse-power per lamp is higher.

It is the writer's practice to allow $\frac{1}{10}$ indicated horse-power per 16 candle-power lamp, or its equivalent, with the usual working margin. The above would indicate

that it is wiser to work a dynamo up to its full power. This, however, is not so. Like all other machinery, dynamos wear better and last longer when worked under power; the extra coal consumed in the boiler in consequence being more than counterbalanced by the saving in repairs and avoidance of breakdowns.

CHAPTER VII.

FAULTS, OR CAUSES OF FAILURE, AND HOW TO REMEDY THEM.

PERHAPS the most troublesome matter with which the marine engineer, who is in charge of an electric light apparatus, has to deal, is that of breakdowns, the failure of any individual or group of lamps, or of the whole apparatus.

In many instances these failures give no warning. A lamp suddenly ceases to burn, or the dynamo refuses to furnish any current, and there is apparently no reason for the failure. As with most other apparatus, however, careful observation will generally give plenty of warning, and will, in most cases, allow of timely repairs being made, so that actual breakdowns may be avoided. The object sought for in the present chapter will be to endeavour to show engineers who have charge of electric light apparatus where to look for possible causes of failure.

All failures of electric light apparatus arise from one of the following causes:—

The severance of a conductor, or its equivalent, the introduction of a high resistance into some part of the circuit, of which the lamp or lamps form a part; or the failure of the insulation of some conductor, so that the

current passing through it does not reach its proper destination at its proper working strength. Stated shortly, a lamp or group of lamps cease to give light because they do not receive the current necessary to enable them to generate the required amount of heat, and this may arise either from the resistance of the circuit of which the lamps form a part having been increased very much, or from the current destined for them, or a portion of it, having passed by another path. The same result is, of course, obtained if the dynamo itself does not furnish sufficient EMF to drive the necessary current through the circuits which are supplied by it. The causes, however, of this failure of the dynamo are exactly the same as those already given for the lamps, viz. either an increase of the resistance offered to the passage of the current in the coils of the armature or field-magnets, or the insulation of the coils or of some portion of the apparatus connected with them, such as the terminals, brushes, etc., having been wholly or partially destroyed. In some cases, as will be easily understood, one of these causes leads to the other. Thus, the failure of the insulation of a cable or a wire, or of a joint, by admitting moisture, may lead to the partial or complete severance of the conductor: also, the severance of a connection, if followed by sparking between the severed portions of the apparatus, may lead to the destruction of the insulation in the immediate neighbourhood.

Taking a numerical example, which will make the matter more easily understood. Assume the EMF at the terminals of the dynamo to be 60 volts, and the combined resistance of any individual 16 candle-power lamp when

burning, with its cables and connections, to be 60 ohms, the current passing under normal conditions would be 1 ampère, using the formula $C=\frac{E}{R}$. Now if from any cause the value of R is increased, say by a portion of the wire having been partially or wholly eaten through, leaving either a needle point only for the passage of the current at that particular place, or obliging the latter to pass through a small length of salts of copper, if it is to reach the lamp at all, then in either case the value of C must go down, and the light given by the lamp becomes less. Take the amount of this increased resistance at 30 ohms, the current passing will now be only $\frac{60}{90}=\cdot 66$ ampère. But here another phenomenon comes in, viz. the increase and decrease of the resistance offered by the filament itself under different temperatures. As the temperature of the filament rises, its electrical resistance falls, and *vice versa*, so that everything which by increasing the total resistance of the circuit lessens the current strength passing through a lamp, also indirectly further lessens that current by increasing the resistance offered by the filament itself. Further, it will be remembered that the heating effect in any conductor, due to the passage of an electric current through it, depends directly upon the square of the current strength × by the resistance of the conductor itself, so that a comparatively small increase in the resistance of the circuit will make a considerable difference in the light given out by the lamp. A complete break in the conductor is equivalent, of course, to the introduction of an infinite resistance into the circuit, so that the formula works out in the case before us

$C = \frac{E}{R} = \frac{E}{\infty}$[1] $= 0$ which is practically 0. To apply figures to the leakage case is not quite so easy, but it will perhaps be better to give them. Leakage from an electric conductor is very similar to leakage from a steam or a water pipe, except that, instead of leaking into the surrounding atmosphere, the current passes across from one cable, or one branch wire, which is in connection with one side of the dynamo, to the cable or wire connected with the other side. But, just as with steam or water, it is the loss of pressure which is produced by the leak which causes the apparatus (in this case the lamp) to refuse to work, or to work badly.

Take the case of a steam pipe supplying an engine at some distance from the boiler, say the steam winch that is used for raising the anchor, and suppose that this engine works well with a pressure of 80 lbs., but there is a bad leak just before the steam pipe reaches the engine, reducing the pressure to 60 lbs., the engine then works badly. The pressure is reduced by the leak drawing away steam from the boiler, reducing the initial pressure there, and adding to the frictional charge for passage through the steam pipe. So with the case of a leak between two electric light cables. The additional current passing through the cables, owing to the presence of the leak, adds to the charge upon the initial EMF, owing to the passage of the current through the cables in opposition to their resistance. To take another numerical example, suppose the EMF at the terminals of the dynamo to be 62 volts, and a particular pair of cables to be supplying current for 30 lamps, requiring an aggregate

[1] The mathematical symbol for infinity; a resistance infinitely great.

of 30 ampères; let the joint resistance of this pair of cables, up to the point where they commence to distribute, say between the engine-room and the saloon, be ·05 ohm. The charge upon the initial EMF for the passage of the 30 ampères through the cables will be 1·5 volts, leaving the voltage or pressure at the entrance to the saloon 60·5 volts. Now, suppose that a leak arises about half-way between the dynamo and the saloon, and that the resistance offered by this leakage path is 6 ohms. You have then roughly, 10 ampères passing through the cables up to the leak, and through the leak itself, in addition to the working current of 30 ampères. That is to say, up to the point where the leak is, a current of 40 ampères is passing through the cables. The charge for this current passing through the resistance ·025 ohm, half that of the cables up to the saloon, will be $= \cdot 025 \times 40 = 1$ volt. The charge for the original 30 ampères passing through the remaining length of the cables will be $= \cdot 025 \times 30 = \cdot 75$ volt, so that the current will arrive at the entrance to the saloon at a pressure of 60·25 volts instead of 60·5 volts, and the lights inside the saloon will not be as bright as usual. If the leak happened to be just before the cables entered the saloon, the additional charge upon the voltage would $= \cdot 05 \times 10 = \cdot 5$ volts, while if the cables, instead of being large for the work, as indicated by the figures chosen, had been smaller, the effect would be much more serious. Suppose the resistance of the cables had been ·5 or even 1 ohm, in place of ·05 and the leak had arisen just where the cables enter the saloon, the additional charge upon the voltage would have been 5 volts and 10 volts respectively, bringing the voltage inside the saloon down to 57

volts and 52 volts, which would cause a very serious diminution of the light given by the lamps. It is, perhaps, well to pause here to note two points. First, if the cables are large in proportion to the current they are to carry, and, therefore, the charge made upon the initial EMF for the passage of the current through them is small, it will require a comparatively large leakage current to perceptibly reduce the working voltage at the lamps.

Secondly, a bad leakage may lead to a very serious danger from the heating effect caused by the leakage current. The heat developed by a current of 10 ampères passing through a comparatively high resistance, such as damp wood, is considerable, when the latter is in a confined space, and the time unlimited. The writer believes that many serious fires have been caused by these heavy leakage currents in the early days of electric lighting.

Next, as to how to discover a fault, and to repair it.

First, in every case, get all the information available before going in search of your fault. In many cases, if you have all the details of what a lamp or dynamo is doing, and what they will not do, you are more than half-way to the discovery of your fault.

If, for instance, a particular lamp of a group will not burn, while the others do, it hardly needs any very deep thought to see that the fault will probably lie in that portion of the apparatus which is connected only to that lamp. So, too, if all the lights go out, it is more than probable that the dynamo is at fault.

Faults in the Dynamo.

First, disconnections, or the introduction of additional resistance in the path of the current. These may occur at

the brushes, where they bear on the commutator With some forms of dynamo, where the sparking is very slight at the brushes, and the latter bear very lightly on the commutator, they may work clear, and yet look as if they were still collecting as usual. For ship work, and for other places, where a dynamo has to be placed in the hands of untrained men, the writer prefers that a slight spark shall always be visible at the brushes, so that it can be seen at a glance that the dynamo at least is doing its work. The commutator wears away rather faster for the presence of the spark, but in the writer's opinion the small extra cost is well earned. The only way to ascertain if the brushes are not working in proper contact with the commutator is to put more pressure on. If the lights, which were previously out, now light up, it is probable that the cause of the failure has been found. With those forms of brush-holder, in which the bearing of the brush upon the commutator depends upon the tension of a spring, this should be examined occasionally to see that it does not suddenly develop a fault of this kind. Springs of all kinds, as marine engineers well know to their cost, lose their tension in the presence of heat; and, in addition to this, the passage of an electric current through any metal tends to render it brittle, and liable to break off short.

The next point at which a disconnection can occur is at the surface of contact between the brush itself and its holder. If the former be held loosely, or the screws which keep it in place be not properly tightened, a disconnection may occur between the two, either from the loose contact or from the presence of dirt between the opposing surfaces. In use—all of these parts of the

apparatus should be kept scrupulously clean and free from oil. Oil is a very poor conductor, unless largely mixed with metal dust, but on the other hand, when carbonised by the passage of the current through it, as sometimes happens, it becomes a very bad insulator.

Next, the connection between the brush-holder itself and its support, which is usually a spindle of some kind on which the brush-holder is held by some form of screw attachment. If it be loosely held, or dirt be allowed to collect between the two, the same result, whole or partial disconnection, ensues. Next, the connection between the brush-holder and the wire coils of the field-magnets. Where a rocking lever is used with the brush-holders, so as to enable the lead of the brushes to be changed, as is now the almost universal practice, the connection between the coils and the brush-holder is usually made by means of a flexible cable. This flexible cable consists of a number of small wires stranded together and insulated over all, the attachments to the brush-holders and to the ends of the wire coils on the field-magnets being made by means of metal washers usually attached to screw terminals. The same remark applies here as before. If these washers, or whatever the arrangements may be, are not screwed up tight, or if oil or dirt be allowed to collect between the surfaces across which the current has to pass, resistance is added to the circuit of the magnetising coils, less current passes through them, and the magnetic field being thereby weakened, the EMF generated by the armature at a certain speed is lessened, and the lights go down.

Other points at which disconnections may occur are, the connections of the ends of the coils on the different

legs of the field-magnets to each other. These connections are best made by the ends of the wires being carefully scarfed, bound together with fine wire, and soldered; the finished joint being well wrapped with insulating tape. It is often, however, very inconvenient to have permanent joints of this kind, as in the event of the dynamo requiring to be taken to pieces, as not unfrequently happens when the armature is taken out, in many forms of dynamo, the joints have to be broken and re-made. For this reason the connections between the wires on the different legs of the field-magnets are made by means of small hollow brass cylinders, with two screws passing transversely into them. The ends of the wires are passed into the barrels of the cylinders and held there by the pressure of the screws. If these latter work loose, or dirt and oil be allowed to collect inside the barrel, the same result that has been already detailed will follow. The magnetising current is lessened, and with it the EMF generated by the dynamo.

The next point where a disconnection may occur is at the terminals of the dynamo, the points to which the cables leading to the lamps are attached. It is also very general to make the attachment betwen the main coils of the field-magnets, those which are to lead out to the outer cables, the series coils, to metal washers, which form part of the terminals, and are held in place by the fixed screw attachment of the terminal itself. A loose screw or dirt here will do the same mischief as before. Similarly with the attachments of the cables to the terminals. These are usually made by cleaning the insulating covering off the ends of the cables for about an inch, twisting the wires together, of which the cable is

formed, and inserting the twisted ends into a hole in the terminal, the cable end being held in place by tightening up a screw provided for the purpose, which jams the wire against one side of the hole and keeps it there. If the insulating covering has not been properly removed, so that some portion of it remains to break the connection between the wire of the cable and the brass of the terminal, or the cable end be loose in its hole, or be covered with oil or dirt, an artificial resistance will be introduced at this point, causing less current to pass out to the lamps, and with the series wound or compound dynamo, less current to pass round the series coils of the field-magnets, thereby decreasing or even extinguishing the lights.

A disconnection may also occur within the coils themselves, but this fault is very rare, and could only happen either from bad wire having been used for the dynamo, or from damp or oil having been spilt over the wires, and given rise to chemical action at some weak point in the wire. Disconnections may also, and often do, occur in the armature. It has already been explained that the ends of the wire coils on the armature are bared of their insulation and connected to the radial arms of the commutator by soldering. It occasionally happens, especially after the commutator has been renewed, the whole of these connections having been unsoldered for the purpose, that one of them may not have been well sweated in. The slot or space left for the wire should be completely filled with solder, so as to hold the wire ends quite firmly in spite of the vibration of the machine, and of the ship. If one connection has been imperfectly made, though the current may pass at first, and the machine be apparently all right, the imperfectly soldered

end gradually works loose, and the machine then refuses to give any current, a slight spark showing only at the commutator, due to the coils that are working.

A disconnection may also take place in the wires on the bobbin itself; but this again would be rare, except in cases where bad wire was used, or damp or oil were allowed to get in.

Leakage faults may occur at any point in the dynamo, where the insulation is either wholly or partially destroyed. The spindle or other support of the brush-holders is always insulated from the rocking lever, or from the frame of the machine where that is used in place of a rocking lever. The insulation consists of a collar of vulcanite, vulcanised fibre, asbestos, or other suitable material. If this be rubbed through by the vibration of the ship, or of the machine, so that the spindle of the brush-holder comes into metallic contact with the rocking lever or the frame of the machine; or if the insulating material becomes perished, or loses its insulating properties from the presence of moisture or oil, so that a connection is formed with the main body of the machine; or if copper dust be allowed to deposit upon the surface of the insulating material, and so form a path for the current;—in either of these cases the current passing from the brushes reaches the field-magnet coils, and the outer circuit — the cables, lamps, etc. — with greatly diminished strength, provided that the two brush-holders are subject to the same fault. Where there is a direct metallic connection between each of the brush-holder spindles and the rocking lever, or the frame of the machine, no current will be furnished by the armature, as no appreciable current can reach the field-

magnet coils, and so no magnetism will be generated. Where only one brush-holder spindle is in connection with the frame of the machine no immediate harm is done, but should a connection be formed between the other brush, or any wire leading from it, to the ship, trouble immediately ensues, sparking, and extinction of the lamps. Where copper dust is allowed to deposit upon the surface of the insulating collars of the brush-holder spindles, sparking across frequently follows, the copper dust forming a path of low resistance on account of its shortness; but being unable to carry the large current that immediately passes, without considerable heat being developed, the metallic dust is usually burnt up at once, and its consumption is followed by a spark passing across the break now made in this branch circuit, the result being that the insulation is often completely destroyed, and the machine then refuses to furnish any current at all. It should be mentioned that some materials, such as vulcanised fibre and asbestos mill-board, which are good insulators when dry, are very bad insulators when wet or saturated with some kinds of oil.

The insulation of the field-magnet coils from the body of the machine may be wholly or partially destroyed by damp, and by certain kinds of oil, especially if copper dust be allowed to settle on them; or by too large a current being allowed to pass through the wires of which they are composed, the cotton covering them gradually becoming charred and falling away, leaving the bare wires touching each other.

For the low voltage existing between adjacent coils of the field-magnets of a dynamo, the charred cotton often acts as a partial insulator, its resistance to conduction

being high in proportion to the EMF present, and a dynamo will therefore sometimes go on working with the coils of its field-magnets very much charred, perhaps requiring a slight increase of speed to maintain the proper EMF. Gradually, however, as the charred cotton breaks into fragments and works clear, the machine fails more and more, until it finally breaks down altogether.

This perhaps requires some explanation. First, as to why the dynamo should break down if the insulation of the coils of the field-magnets is destroyed. It will be remembered that the strength of the magnet-field in which the armature revolves, which is one of the factors determining the EMF generated by the machine, depends upon the current strength passing in the field-magnet coils and upon the number of times this current passes round the field-magnets. The current is made to pass round the field-magnets as many times as the designer of the machine wishes, by having the wire of which the coils are formed, and in which the current is passing, wrapped with cotton or other insulating material, usually cotton; so that, though the successive layers of wire and the successive turns are brought very close to each other, as close as winding will allow, the wires themselves are never in metallic contact. If the wires were bare and clean, and were wound as closely on the field-magnets as they are when covered, the current would pass across from one layer to the other at numerous points, and so would not pass round the field-magnets, consequently the magnetising effect intended to be produced would not be secured. It will easily be seen, therefore, that, as the insulation of the coils of the field-magnets fails, the strength of the magnetic field will also fail, and with it

the EMF generated by the armature, unless the speed of driving is increased.

Then, as to why a thin layer of cotton is sufficient insulation for the coils of the field-magnets, and why even charred cotton may serve for a time, if it can hold its place between consecutive turns of wire. The reason for this is to be found in our old friend Ohm's law. Only a small amount of insulation is required, because only a small EMF is present. Take the case of the shunt windings of the field-magnets, which will, perhaps, illustrate the matter best. The ends of these coils, it will be remembered, are connected to the brush-holders. At the brushes, the full available force of the dynamo is present, but nowhere else. Between either brush and the central piece connecting the ends of the wires on adjacent legs of the field-magnets, only half this EMF exists. If there are four legs to the field-magnets, as in many dynamos, between either brush and the farthest end of the coil on the first leg, only a quarter of this voltage exists, and similarly between the ends of the coils on each leg. In the coils of the shunt windings of a dynamo there are usually a number of layers. Suppose there are ten. Between adjacent turns in two successive layers, only one-fortieth of the full voltage of the dynamo will be present; and if there be one hundred turns in each layer, between consecutive turns of the same layer, there will be only one four-thousandth part. Now turn these facts in figures. Taking our 65-volt dynamo. At the brushes we have perhaps 68 volts, 3 volts being used up in the series coils, making 65 volts at the terminals where the cables are attached. Between one brush and the middle connection of the shunt coils we have 34 volts,

between the ends of the coils of any one of four legs we shall have 17 volts; between adjacent coils in consecutive layers, where there are ten layers in all, 1·7 volts, and between adjacent turns in any layer ·017 volts; which is very small indeed, only about 1-90th the voltage of the Le Clanche cell, the one generally used for house bells. Applying Ohm's law, as described for finding the resistance a pair of cables should have for a certain current to pass with only a certain loss of voltage, but using the formula in this case to find the minimum resistance that should rule between two adjacent turns of wire in consecutive layers as before, allowing for a leakage of one-thousandth ampère,

$$R = \frac{E}{C} = \frac{1 \cdot 7}{\cdot 001} = 1700 \text{ ohms},$$

and this is easily obtained, for the sectional area involved, with a comparatively small thickness of *dry* cotton. If the insulation between the field-magnet coils at any point and the frame of the machine is destroyed, this may do no harm at first, but if a similar connection occur between another coil at some other point and the frame of the machine, between the brush-holder and the rocker, or between some portion of the lamp circuit and the body of the ship, trouble will ensue. Where two connections occur in the machine itself, that portion of the coils which lies between them will be almost entirely cut out, only a small current passing by that path, with the result that the strength of the magnetic field is lowered to the extent of the magnetising force it is deprived of, and with it the EMF. Where the second connection occurs outside the dynamo, heating, sparking, and extinction of the lights will usually result.

A more frequent and far more serious matter is the loss of insulation in any part of the armature. If the insulation between two adjacent sections of the commutator, or between two adjacent coils of the winding on the armature, is destroyed, the result will be that the coils which are included by the unbidden connection will be so heated that their insulation will be burnt completely off, and usually the armature will break down shortly after.

The reason of this is again to be found by a reference to Ohm's Law. It will be remembered that the current passing in any circuit depends upon the formula $C = \frac{E}{R}$ where $C =$ the current, E the EMF, and R the resistance opposed to it. When the dynamo is running under normal conditions, the coils upon the armature form part of the whole circuit, in which are included the series windings of the field-magnet coils where there are any, the cables and the lamps, etc., so that the EMF generated by the dynamo has to work against the combined resistance of all these, the resulting current being of such a strength that the wires on the dynamo carry it without undue heating. In the process of generating the EMF, or generating a current, as it is usually expressed, each coil of wire on the armature lends its aid to the result achieved, so that the total EMF generated is really made up of a number of fractional parts added together, just as the total EMF available at the terminals of a battery of galvanic cells, is made up of the algebraical sum of the EMF's of the individual cells in the battery. In fact, the coils on the armature, the ends of which are connected to adjacent segments of the commutator, each coil

consisting of a certain number of turns of wire, behave in this respect very much like the cells of a galvanic battery.

It will be understood, therefore, that between any two adjacent sections of the commutator of the dynamo, a small EMF exists proportional to the total EMF generated by the armature as a whole. Under ordinary conditions of working, this small EMF only goes to swell the total EMF generated, its coils forming part of the whole circuit. If, however, two adjacent sections of the commutator are connected together, say by a piece of copper having been carried over to the next by the turning tool in the process of turning up, by the radial arms having come into contact, by solder having been dropped between them, or by copper dust having been allowed to collect between two faulty segments, the result is that the small EMF generated by the individual coil is now opposed by a very low resistance, that of the wire of the coil itself, and a very large current will pass, heating the wire often to redness and burning the cotton covering off. To put this again into figures, take a dynamo whose armature has a total resistance between the brushes of ·06 ohm, and which has 60 coils and 60 sections in its commutator. This means that the resistance of each individual coil is ·004 ohm. Take the EMF generated by each coil as two volts, and we have for the current passing in any coil which is short circuited, as it is termed when passing under the brush, applying the formula as before,

$$C = \frac{E}{R} = \frac{2}{.004} = 500 \text{ ampères.}$$

As under the conditions given, the wire on the coils

was intended to stand perhaps 30 ampères in regular work, and, it will be remembered, the heating effect varies as the square of the current passing, other things being the same, we have the heat generated in the short circuited coil to the heat it was intended to carry, as $30^2 : 500^2 :: 900 : 250{,}000$. Roughly, the wire of that coil will be heated to three hundred times the temperature it should have when running under ordinary conditions.

The same thing will happen if by accident the ends of the coils are wrongly connected to the commutator, so that the two ends of one coil are connected to the same segment, this being, of course, equivalent to connecting adjacent segments together in the manner described. Also, when the insulation of two adjacent wires, which are perhaps rubbed together, is destroyed, the coils between the connection will be heated in the same way. So, too, as sometimes happens, if the insulation of the iron core from the wires be destroyed in two places, or in one place if it embraces several turns of wire, the coils which are interposed between the points where the insulation is destroyed, or which are covered by the space where it is destroyed, will be heated in the same manner, and all their insulation burnt off. The iron core in this case acts as the metal connecting-piece between the two coils. This latter fault, which is rare with modern dynamos, may be brought about, in badly designed dynamos, by the heating of the iron core, due to electric currents set up within itself, and to the changes of direction of magnetisation which go on within it during each revolution. The iron core, being a conductor revolving in the magnetic field created by the

field-magnets, generates currents within itself in the direction of the winding of the copper wire coils upon its surface. To avoid this the iron core is also built up either of wire or plates, in such a manner that the circuit in the direction these currents would take is broken up, successive iron plates or turns of the iron wire being insulated from each other. If this is insufficiently done, currents are generated, which circulate in the iron core as a closed circuit, generating heat.

Further, the operation of magnetising any piece of iron appears to consist of a twisting of the molecules of the iron, in the direction of the magnetising force. They try to place their longer axes in this direction. The molecules of the iron core of the armature of a dynamo are magnetised in opposite directions during each revolution. They are turned in one direction under the influence of the north pole of the dynamo, and in the opposite direction under the influence of its south pole. This twisting to and fro, as will easily be understood, generates heat, and the heat is greater in proportion to the impelling force, as compared with the mass of metal influenced. If a high degree of magnetisation is produced, or, as electrical engineers express the matter, if the lines of force passing into the armature core are numerous in proportion to the sectional area of the iron, heat is generated rapidly, and the insulation of the core will be destroyed. The same result may be attained by the use of inferior iron.

The insulation of the iron core is also occasionally destroyed by a burr left on the iron, or a small point of iron left sticking up, which works its way through the covering.

Two faults, which are not common but which may be met with occasionally, are, the dynamo refusing to give any current :—(*a*) Because the wires of the field-magnet coils are so connected that no magnetism, or very little, passes through the armature; and (*b*) The iron of which the field-magnets are composed having lost their residual magnetism, and so the dynamo is unable to build up, as it is sometimes termed. It should be explained that, in order that a self-exciting dynamo may start itself, it is necessary that a small trace of magnetism be left in the iron of the field-magnets. When the armature revolves, this small trace of magnetism creates a very feeble magnetic field in the polar space, causing the armature to generate a very weak current. This weak current passing through the field-magnets strengthens the magnetic field already existing, thereby increasing the strength of the EMF and the current generated by the armature, this again strengthening the field, and so on. Where no magnetism is present the action cannot commence.

Both of the faults mentioned, *a* and *b*, may arise from the dynamo having been taken to pieces to clean, and in the one case (*a*) the connections having been wrongly made on putting it together again ; and in the other from the knocking about, often inseparable from the work of moving heavy masses of metal under the conditions ruling, having assisted the molecules of the iron to resume their natural position of rest, aided possibly by the presence of other masses of iron near. The second fault (*b*) can sometimes be rectified by giving the iron of the field-magnet a smart tap with a hammer. If this does not answer, get a small battery, such as will be described presently, for testing, and pass a current from

it through the shunt coils of the field-magnets for a short time, then run the dynamo again, and it will build up and furnish a current as before.

The fault (*a*) can be discovered best by examination. The connections of the field-magnet coils should be such that, with any one pair of coils (two legs) the ends next the pole pieces should become one north and the other south, under the influence of the existing current. Where there are four coils and four legs to the field-magnets, the winding and the connections must be such that one

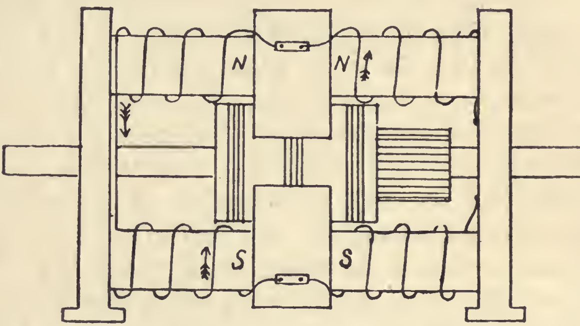


Fig. 97.—Showing Winding of Field-Magnets as they should be.

pole piece is north and the other south. This means that the portion of each magnet adjoining one pole piece will be north, and the outer ends of the same legs south, while the inner ends of the other two legs, those joining the other pole piece, will be south, and their outer ends north. Fig. 97 will show this more clearly. If the connections between the field-magnet coils are such that the ends of the field-magnets adjoining either pole are north on one side of one pole, and south on the other, this will leave the pole piece itself, and the polar space

in which the armature revolves, out of the magnetic field, or only under the influence of the field due to leakage, with the result that no current will be generated by the armature. Fig. 98 shows how the magnetism would go under these conditions.[1]

In what are termed multipolar dynamos, such as the Victoria, where there are four or eight poles of a shoe form, embracing the disc-shaped armature, the same arrangement of connections is required. The two field-magnets, the two bobbins, connected to one shoe must

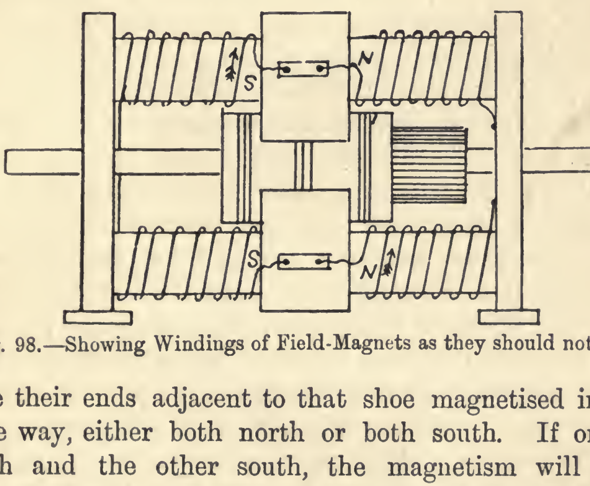


Fig. 98.—Showing Windings of Field-Magnets as they should not be.

have their ends adjacent to that shoe magnetised in the same way, either both north or both south. If one is north and the other south, the magnetism will pass through the shoe and avoid the armature, as with the two-pole dynamo. To find whether this is so, trace the connections of each coil, remembering the rule shown in Fig. 1. If a wire carrying a current passes *from* you *over* a piece of iron, the north pole is on your left, if it passes *under from* you, the south pole is on your left.

[1] Most modern dynamos are made with field-magnets of the single horse-shoe type, so that this fault is now rare.

Faults in Cables.

These have been partly indicated already. Disconnections occur principally at joints, where the insulating envelope of the cable has been broken for the purpose of connecting a branch cable. If the joint has not been well soldered, or if it has been soldered with spirits, and the latter have not been thoroughly burnt off; if the joint has not been completely covered, and wet has crept in; if, as not unfrequently happens, some of the wires have been nicked when the covering was removed, and have broken off short; in either of these cases you may have a disconnection completely cutting off the lamps supplied by that particular pair of branch cables. With indiarubber-covered wire, also, the rubber is apt to perish with the different changes to which it is exposed, to crack under the very heavy strains to which it is sometimes subject; and in either case, if water, especially sea water, finds its way through the opening made for it, as it undoubtedly will do, the wire itself will be gradually eaten in two, and you may then have a disconnection of the main cable.

The smaller branch wires, those leading directly to the lamps, are perhaps more liable to be disconnected than any others. They are often more exposed to wet and to mechanical injury than the main cables. Frequently they are exposed to sharp twists tending to kink and break the wire, and to burst the insulation. The attachments of the small branch wires to the switches are also possible sources of failure by disconnection.

Leakage between cables and branch wires may occur from their not being properly insulated in the first place, or from the insulation not being adapted for the climates the ship has to visit. It is more frequently due to defective joints, one in each cable, lying near to each other, or to the chafe of the cable on some sharp edge of iron in the working of the ship.

It must be remembered that if the insulation is weak when the cables are first laid, the mere presence of the electric current in them will gradually break it down altogether.

Faults in Lamps, Switches, and Fittings.

Faults in lamps and switches are rarely other than disconnections. Leakage may occur across the terminals of a lamp, but the conditions under which it could take place would not often happen on board ship. Leakage across a switch, or across a cut out, may put them out of action. That is to say, the leakage current across a switch, if it is sufficient, if the resistance of the switch when "Off" is sufficiently low, may cause the lamp the switch is intended to control to burn even when supposed to be turned off; or, if the leakage is not so great as that, it may cause a current to be passing through the lamp when it is not in use, of insufficient strength to cause it to give out light, but sufficient to reduce its life, and if multiplied to add to the useless work done by the dynamo. If the lights are arranged on the single wire system, or one cable be in connection with the body of the ship, say through its insulation having given way or been rubbed through, and the insulation of the

switch itself, from the iron work of the switch, be defective —a serious leak may take place.

But what are most to be feared in connection with switches are, the ends of the wires working loose, owing to their being imperfectly connected, or to the working of the ship in a heavy sea-way, leading to sparking and attendant troubles.

Disconnections in lamps arise from the platinum wires breaking off short at the glass, or becoming disconnected from their places, where capped lamps are used. A disconnection may also, of course, take place in the filament itself.

The remarks that were made about faults in switches apply equally to cut outs. Double pole switches and cut outs are of course liable to leakage across the base on which they are mounted.

The most frequent and the most troublesome faults that occur with lamp fittings are in the lamp-holders. In order that the lamps may be easily and quickly replaced, it is necessary that there should be a certain amount of looseness between the terminals of the lamp and their immediate connecting pieces in the lamp-holder. Where lamps with loop terminals are used, the hooks which engage the loops sometimes jerk clear of them, or one of the hooks will do so, with the result that the lamp is extinguished. It sometimes happens, also, that where a lamp hook does not actually disengage itself, it becomes sufficiently loose for a spark to pass, fusing the hook and the loop; sometimes welding them together, at others dropping the lamp out altogether. Where capped lamps are used, the plungers which are arranged in the lamp-holders to make contact with the

plates on the base of the lamps sometimes do not do so, with the result that occasionally sparks pass, and trouble results; while, at other times, the lamp simply goes out.

The insulation of lamp-holders is also sometimes defective. The space available for insulating the terminals and working parts from each other being very small, if the material used for the purpose loses its insulating properties, only partially, or not enough of it is left between the two terminals of the lamp-holder, which, it will be remembered, are in connection with the opposite terminals of the dynamo, the presence of the current gradually destroys what is left, and sparks pass between the two. The small connecting wires leading into the lamp-holder are also liable to become fruitful sources of trouble, if their insulation is defective, either as made, or from rough handling in fitting up, or if the long ends have been left bared, so that the wires can touch the brass frame of the holder, where this form is used, or even when one wire touches, sparking and short circuiting may result. Where these wire ends work loose also, sparking results, as before, between the wire and its terminal screw.

How to Discover Faults and to Repair Them.

For discovering faults due to disconnection, there is one universal rule, and a very simple one:—

Put a current on the wire where the disconnection exists, and test by making artificial connections so as to complete the circuit at successive points, working outwards from your source of current, and using some instrument that will denote the presence of a current,—

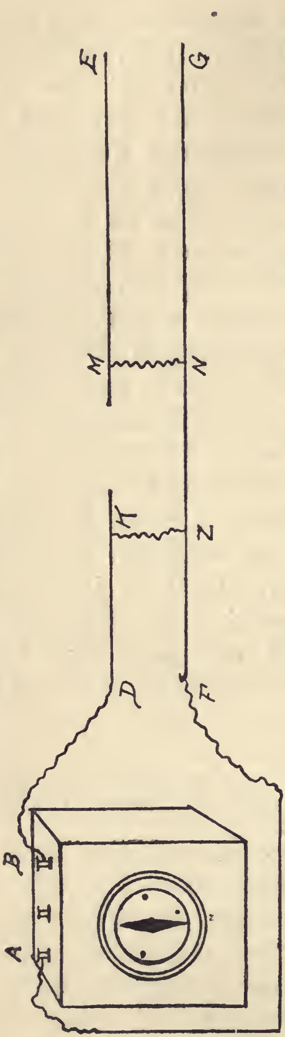


Fig. 99.—Showing how to test for a break in the Circuit.

when you have found two places, at one of which your instrument shows that you have a current passing through the temporary circuit you have made, and at the other your instrument shows that no current is passing, your fault lies between the two points.

Fig. 99 will show this more clearly: ABC is an apparatus consisting of a battery and galvanometer in one case, the terminals shown being so arranged that a wire connected across them completes the circuit of the battery through the galvanometer. Connect the terminals A and B to the wires in which a disconnection is present, as shown; then, as will be seen, when the two points KZ are connected, a current will pass through the galvanometer, and will be indicated by the deflection of the needle. If the connection between K and Z is removed, and one made between M and N, no current will pass through the galvanometer, because of the break

between M and K. Now, to apply this rule, first to the dynamo. Take your testing apparatus, having attached the ends of two short pieces of small branch wire to the two terminals, baring them of insulation for that purpose; also bare the other ends for about an inch, and see that these ends are quite clear of each other, and of everything else, in each case. If you have left some rubber on the wire, either where it is connected to the terminal, or at the end left free for testing, you will probably spoil your test, by fancying you have a disconnection in the machine, while all the time it is in the testing apparatus itself. Stop your dynamo, if that has not been already done, and proceed to test through as follows. Connect one of your test wires to one brush, having placed both brushes clear of the commutator, and then touch the other test wire on each point of connection in succession, say on the brush shoe, its spindle, the connection to the flexible cable leading to the series coil of the field-magnet, the connection between this and the series coil, the connection between successive legs of the field-magnets, and so on round to the other brush, or to the terminal. Suppose there is a disconnection between the wires on two adjacent legs of the field-magnets, as already described, the galvanometer needle would be deflected at each point up to the junction, and it would be deflected on one side of the junction and not on the other, showing plainly the fault to be in the junction. It will be seen that the successive points named, being all in metallic connection with each other, touching one of the testing wires upon them while the other remains connected to the brush, completes the circuit of the testing battery through the galvanometer, just as if a short piece of wire

had been connected across the terminals of the instrument. Care must be taken, in making the test, to press the end of the testing wire *firmly* upon each point, and to have a clean metallic surface to test to. The presence of oil or dirt will mislead, as you will again imagine you have a disconnection in your dynamo, while you really have one between your test wire and the dynamo. Care must also be taken that the fixed testing wire is making good clean metallic connection with the brush also, or the test will be of no use.

If the testing apparatus be fitted with two circuits, as already described in Chap. VI., the test for want of continuity, or disconnection, should be made with the circuit of low resistance; as if the other circuit is a sensitive one, as it ought to be, it may also give misleading indications. Perhaps it will be best to describe the testing apparatus here.

As already explained, it consists of a galvanometer and battery in one box. The galvanometer has already been described on p. 209.

Such an instrument is put in a box, with two or more cells, and the lid of the box left free to open, the galvanometer being removable, or the whole are enclosed in one case held by screws. The author prefers the latter plan. The cells used may be Le Clanche cells in ebonite cases, sealed over, or they may be one of the new form of dry cells. As some forms of these latter, in which a paste of gypsum or other material is used, in place of liquid, have been very much improved, the author prefers them to the Le Clanche. The Le Clanche, if made small, does not last, nor does it stand well at all, if sealed over; while, if made large, it is bulky to carry about. Figs. 100 and 101 show this apparatus as arranged by the writer. It will

be evident that with the above it is quite easy to test any wire or apparatus in which a disconnection exists, such as a switch, a lamp-holder, or a branch cable, and to localise the fault with unerring certainty.[1] In some cases it is necessary to remove the insulation of the cables or wires in order to finally localise the disconnection, but this should not be done until a very careful examination has

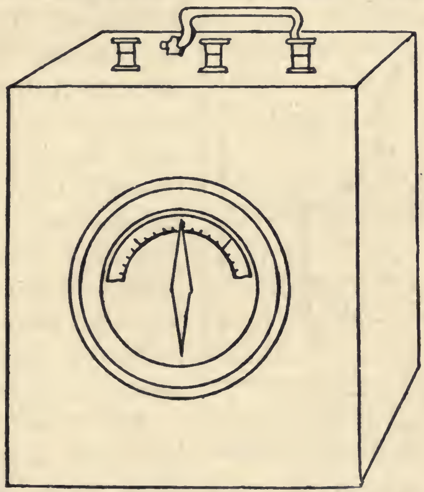


Fig. 100.—Showing Outside View of the Author's Testing Apparatus.

been made. In fact, it may be taken as an invariable rule that very careful examination should precede testing.

Testing for a disconnection in the armature requires rather different treatment to that for the rest of the apparatus, because there are two circuits for the testing current to pass through. The current passing from

[1] The author has recently introduced a similar testing set, but with a small dynamo giving 100 volts, in place of the battery, it answers better for leakage tests.

the brushes is made up of the current generated in the two halves of the coils of the armature, and when a current is passed into the armature, say when the machine is run as a motor, the incoming current divides between these two halves of the coils, and the testing current does the same. If, therefore, we attempt to pass a testing current through, hoping to find a break, we cannot do so, as, though the current cannot pass through that half of the armature in which the break lies, it passes freely through the other half, and our needle is deflected just as if there were no break, and this is the case when we even have only two or three coils interposed between the testing wires. The remedy is found by making a second break, unsoldering one of the connections to the commutator radials, and separating the coil ends. We now connect one of our test wires to one of the separated wires, and test round with the other wire, touching it firmly on each commutator section as before. Up to the moment when we reach the disconnection we are looking for, the deflection of the needle of the galvanometer will be the same at each test, but immediately we pass the break the deflection will be 0, and a more careful examination will now usually discover the fault.

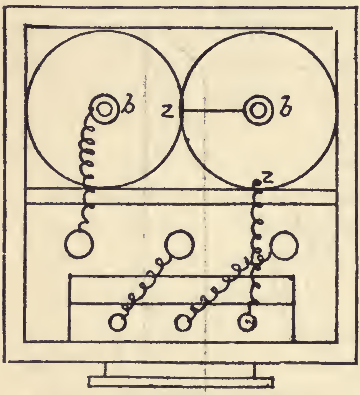


Fig. 101.—Showing Plan of the Inside of the Author's Testing Apparatus.

For leakage faults the same testing apparatus is used, but with the fine wire coils the long circuit, instead

of the short circuit of the galvanometer. The testing apparatus is prepared in exactly the same way as before, but the testing wires are attached to the two terminals of the apparatus, which include the fine wire coils of the galvanometer and the battery.[1]

It will be remembered that our object now is to find a connection between two conductors—such, for instance, as the spindle of the brush-holder and its rocker, from which it should be insulated, or between the wire coils of the field-magnets and the frame of the machine. To make the test, say from brush-holder to rocker, we press the bared ends of our testing wires *firmly*, one on the brush-holder spindle and the other on the rocker, being careful to press the wires upon *clean, bright* surfaces of the metal in each case. As before, a layer of oil or dirt, though it will not make so much difference as in our test for disconnection, may make us think that we have not got so bad a fault as we really have.

If, when we make the test, the needle of the galvanometer is deflected, it is a sure sign that the insulation between these two parts of the apparatus is defective. The same remark applies to the test for connection between the coils of the field-magnets and the frame of the machine. It is best, however, in making tests of this kind, to arrange, if possible, before testing, that no other conductors except those actually under test can form part of the circuit. Thus, the field-magnet coils should be disconnected from the brush-holders, before the test is made between them and the rocker. Similarly the coils themselves should be disconnected from each other. If

[1] Where an Ampère Meter is in regular use, any serious amount of leakage denoted by the increased current shown on its dial.

this is not done, misleading results will be experienced. Thus, the brush-holder rocker being in metallic connection with the frame of the machine, a connection between the coils on the field-magnets and the latter will show as a connection between the brush-holder and the rocker. Suspected connections between the terminals of the dynamo and the body of the machine, between the series or main and the shunt coils, between the two sides of a double pole switch or double pole cut out, between the terminals of a lamp-holder, may all be tested for in the manner described; but always on condition that the two conductors between which the test is to be made are isolated from each other as far as possible.

So, too, a connection of high resistance between either cable and the body of the ship, where two cables are used, or between the one cable and the body of the ship, where the single wire system is used, can be detected and repaired before it has time to do any mischief.

The position of such a fault, too, can be localised with unerring certainty, by dividing the cables up and testing each branch in succession.

It is here where the system of double switches, viz. a switch on each cable, comes in useful. Take the case of a ship wired on the double wire system, and suppose that the engineer in charge has reason to suspect a connection between one cable and the ship. He would be led to suspect such a connection if, on accidentally touching one wire on some part of the iron framing, or of the machinery, a spark passed. Taking the testing apparatus, he would first test at the dynamo, from either terminal to the frame, having the cables leading to the lamps disconnected from the machinery, if possible. If with all

the cables disconnected from the dynamo he found a connection between one of the terminals of the latter and its framework, the fault would be in the dynamo, and he could proceed to test through it. If the dynamo tested clear, he could test each cable in succession, keeping the others clear. Having found the pair of cables on which the fault existed, say it was the pair feeding the forecastle, he would now go to the first point where branch cables are taken off, and cut off that branch by means of the switches, or if there are not two switches, by breaking the joint to the other cable, the one to which there is no switch. He can now test both the branch and the main cables separately. If the main cables now show clear, while he obtains a deflection between either branch cable and the body of the ship, the fault is in the branch. If the branch shows clear while the main cable still shows a deflection when connection is made to the iron, the fault is on the main cables. If both show a deflection, it means most probably that the insulation of the cables and branches are all bad alike, and should be renewed, though it may of course mean that there is a connection with the ship on each. It will easily be understood that the connection between the two cables, by way of the lamps and fittings, necessitates the disconnection of both branch cables from their mains, as otherwise a bad fault on the main cables might show as a not very bad fault on the branch cable. For leakage faults, however, it is wisest to use the long circuit of the detector galvanometer with the current from the battery as a preliminary, and to follow where it can be done, and especially in suspicious places, with the full voltage of the dynamo, or with a small hand dynamo, giving 100 volts. Voltage has a very

marked effect upon leakage currents, and upon insulation resistances that are breaking down under the strain of working. 100 volts and even 60 volts will often show a serious leakage current with the same galvanometer that shows no deflection with a battery current. Use, then, the battery for testing as a precautionary measure whenever you can spare the time,

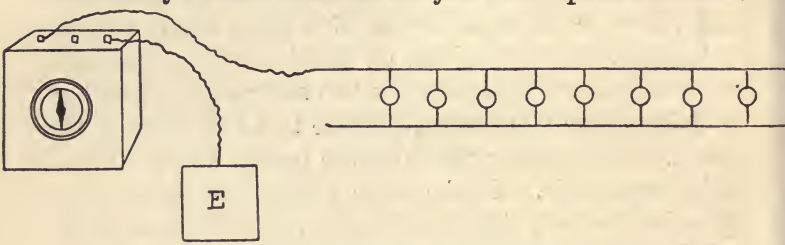


Fig. 102.—Showing the Arrangement for Testing Cables or Leakage.

but follow with the dynamo current wherever you find the smallest shake of the needle, and even where you do not, in important places.

The same instrument may be used for testing with dynamo current, without any change, as the current which passes will not damage the battery. Do not use the small dynamo testing set in connection with the working dynamo current. To test for connection between the dynamo wires and the frame of the machine, for instance, using its own current for the purpose, and leaving the dynamo running, place one of the test wires firmly on each of its terminals in succession, and touch the other test wire lightly at first, on the body of the machine. If there is any connection present between the wire coils and the iron, a spark will pass on touching the frame with one test wire, when the other is con-

nected to one of the terminals of the dynamo, and the needle of the galvanometer will be thrown sharply over. If no spark passes, the end of the testing wire may be pressed firmly on the body of the machine, when sometimes a small deflection, showing a connection of high resistance will result. Where there is a connection between the coils or one brush and the frame of the machine, a deflection will be shown from one terminal only, as there is a short circuit, a connection of low resistance, between the other terminal and the frame of the machine.

For testing the leakage of cables to the ship or to each other, using the dynamo current, the testing apparatus is connected between one terminal of the dynamo and one end of one cable, it having been disconnected from that terminal of the dynamo for the purpose, the other terminal of the dynamo being temporarily connected to the frame of its own machine, the iron deck, or any other convenient place. If there is a connection between the cable and the ship, or if the insulation of the cable is defective, the galvanometer will denote the fact, and will roughly indicate the seriousness of the fault by the amount of its deflection. Where the object is to find if leakage exists between the two cables, the second cable remains connected to its own terminal on the dynamo, but the lamps must be removed from their holders during the test.

The actual point where the leakage exists may be found, or at any rate the length of cable in which it exists, by eliminating each branch and each section, either by switching off or by cutting. It is especially of importance to test with the whole voltage available, for lamp fittings and other places, where wires or pieces

of metal can get across two points that are supposed to be insulated from each other. It will sometimes happen that the end of a wire will be left nearly touching some part of the apparatus attached to the opposite side of the circuit. A battery and galvanometer test would show this all clear, yet, on starting the dynamo, there would sooner or later be a breakdown at that point from a spark pass-

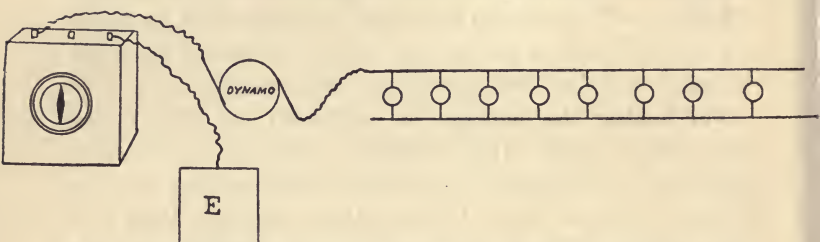


Fig. 103.—Showing Arrangement for Testing Cables for Leakage, using the Dynamo Current.

ing across the small interval. On testing with 60 or 100 volts the spark passes at once, and the apparatus can be put right before it has time to do any harm.

The possibility of a connection between the shunt and main or series coils of a compound wound dynamo has been mentioned, and it may be as well to show how such a fault would affect the working of the dynamo. The fault could be created, and has been, by the connecting pieces between the ends of the coils on the two legs of the field-magnets either coming into direct metallic contact, or being brought partially into connection with each other by the mass of oil that sometimes is allowed to collect in these places. It has been before explained that oil is a bad conductor, but after an electric current has been passing through it for some

time, such as would pass under the conditions named, it appears to change its nature, and to become a moderately good conductor, especially if there is much dust about to deposit on the wet oily surface. The effect of the connection between the shunt and main coils is to practically cut out the shunt windings on one or more legs of the field-magnets; the current, on arriving at this connection, passing almost entirely through the main wire, only a very small portion passing through the shunt, the result being that the magnetic field within the polar space is weakened in proportion to the number of ampère turns which are lost, and the armature has to be run faster to make up for the loss. An accompanying indication of a fault of this kind would be, the shunt coils that were cut out keeping very much cooler than usual when in work; while the others would be hotter, as they would have to carry an additional current strength in proportion to that cut out. Thus, suppose that with an EMF of 70 volts at the brushes, the total resistance of the shunt coils was 35 ohms, giving a shunt current of 2 ampères. If half the shunt coils were cut out, the same voltage being present, the current the remainder of the coils would have to carry would be 4 ampères, which would give four times the heating effect if the resistance of the coils that were carrying the current remained constant. Two points have here to be noted, however. As half the coils are cut out, and the other half carry double the former current, the magnetising power is the same, and the machine should not have to run faster in consequence. But the machine nearly always does have to run faster, sometimes very much faster, when such a fault is on—why is this? The reason is to be found in the property

which has been already mentioned, by reason of which increased heat in a conductor, no matter how the heat is produced, even by the passage of a current through the conductor, increases the resistance offered by the conductor, so that in the case mentioned, while the number of shunt coils carrying the current would be halved, the current passing through them would not be doubled, or even approximately so, unless the gauge of the wire with which the shunt coils were wound was so large, and they were so favourably placed, that doubling the current would make no appreciable difference in the heating effect, a case that would never occur with practical dynamos, however high the so-called efficiency may be.

Another general indication of leakage, or defective insulation somewhere, and usually in the dynamo itself, is the sudden or even gradual increase of the sparking at the brushes. Care must, of course, be taken not to mistake a badly trimmed brush, or an improperly set rocker, for leakage. Either of these will cause sparking, as also will dirt on the commutator, or a badly adapted brush that will not follow the wear of the commutator. But, having attended to these matters, and being quite sure that they are in order, if the dynamo either suddenly starts sparking heavily, and no amount of coaxing at the brushes will reduce it for long, or the sparking at the brushes is observed to gradually increase day by day, no matter what care is given to them, test your dynamo for leakage without delay, and look out for the first opportunity of getting rid of the leak when you have found it, as leakage always increases if allowed to go on, just as the friction of the water or steam passing through a small

hole in a pipe, gradually causes an increased leak by increasing the size of the hole.

Look well round your dynamo for copper dust, and for the dirty markings left by the spark in its passage. These will generally be sure guides as to where the leak is.

Perhaps a word about the form of brushes and their regulators will not be out of place in conclusion. There are different ideas as to what a brush should do, and how a commutator should look after running. The following, however, are fairly agreed upon:—

The brush must collect the current with the least possible friction on the commutator;

There must be the least possible sparking between it and the commutator; and

It must follow the wear of the commutator as long as it is safe to run the latter.

Further, it is generally agreed that the commutator must wear down and be renewed in time. When it comes to arranging details, however, there is considerable diversity of opinion. Some makers sacrifice everything to reducing the sparking to the lowest point. Others, again, lay stress upon keeping the surface of the commutator bright, smooth, and cylindrical. Both of these are good. The wear of the commutator and of the brushes is directly in proportion to the sparking, while it always looks well to see a commutator nice and clean, and cylindrical. But it is a question whether these advantages may not be too dearly bought. When the sparking is reduced to a certain limit, the saving of copper from a still further reduction is not very serious, while the attendance required to secure the additional saving is sometimes very heavy. In order that the

sparking shall be at a minimum, the dynamo must be very carefully, often expensively, constructed, and the brushes must be arranged to impinge exactly on the spot where the current reverses. As this spot changes with every change of load, sparking is set up constantly, unless an attendant is at hand to alter the rocker as soon as he sees a spark appear. The surface of the commutator, too, requires very considerable attention, every little irregularity being carefully removed, or it will lead to a spark, which again entails labour.

The form of the brush naturally has a good deal to do with the question of sparking, and with the wear of the commutator. Again there is a great diversity of opinion on this point. One thing is conceded, viz. that there must be a certain amount of spring in the brush or its holder, or the friction on the commutator will be too great. If the brushes are rigid, the brush-holder must have a spring which gives under the pressure of the moving commutator. If this spring is too weak, the brush jumps and sparks. If it is too strong, there is considerable friction. Further, with rigid brushes, such as those made of copper plates, or of carbon, any irregularity in the commutator is serious.

The writer prefers brushes made up either of a number of wires with their ends soldered together, or of very fine wire copper gauze. Wire gauze brushes are very generally used now, but carbon brushes and copper brushes with carbon tips are coming in.

CHAPTER VIII.

THE USE OF THE ELECTRIC LIGHT IN PETROLEUM SHIPS.

It will be within the memory of the readers of this book that, a few years since a somewhat disastrous explosion occurred on board the s.s. Tancarville, when under repair in dry dock at Newport.

As the electric light was in use in one of the petroleum tanks at the time when the explosion took place, the writer was requested by the owners of the dry dock to inspect the apparatus, and to report whether it was probable that the explosion had been caused by it.

Evidence was found of a powerful spark having passed between one of the flexible leads which furnished current to an incandescent lamp in one of the tanks, and some other conductor, such for instance as the combing of one of the hatchways or a beam, or in fact some part of the frame of the ship.

The two petroleum experts, however, Dr. Dupré and Professor Redwood, who were called by the Board of Trade, at the inquiry which was held shortly after, were of opinion that at the point where the electric spark could have passed, no oil vapour that was either inflammable or explosive could have been present. In the course of his examination, Dr. Dupré expressed the

opinion very strongly—that the electric light should not be used, under any circumstances, on board ships carrying petroleum as a cargo.

It is with the view of examining this question, and of determining if the electric light is or can be made safe for steamers carrying cargoes of this kind, and what the conditions of safety are, that the writer ventures to present the following remarks for the consideration of marine engineers.

At the request of the owners of the dry dock, Messrs. Mordey & Carney, Ld., the writer also made a series of careful experiments to determine exactly the conditions under which a spark might be expected to pass, and the conditions under which it would ignite the inflammable vapour of petroleum, if present.

It will be well known to marine engineers that the petroleum carrying ship of the present day is made up of a series of huge tanks, the skin of the ship forming one boundary of each tank, the other boundaries being thin iron bulkheads, with valve doors for communicating between the tanks.

The whole ship is, in fact, one large tank divided into compartments, with space taken out for the engines, pumps, living room, and ballast tanks.

As is also well known, the vapour of petroleum is very insidious. It works its way through air-tight joints, through bulkheads, through covered hatches, and is found in every part of the ship.

Even when a tank is supposed to be empty, after the powerful suction pumps that are employed have drawn off every drop of the oil that can be obtained, the vapour still continues to rise, and may be smelt for days and

even weeks after the cargo has been discharged. In fact, it is doubtful if it is possible to get rid of all the vapour, once a ship has carried a cargo of petroleum.

It will easily be understood that between decks, especially in the neighbourhood of the hatchways, there will be a constant stream of vapour rising and mixing with the surrounding atmosphere there, and that this space, and, to a less degree, the upper deck above, is very dangerous, owing to the continual presence of this mixture of vapour and air.

Where, too, a tank is partly full of oil, the remainder of the space within the tank which will naturally be filled with the oil vapour, and as much atmospheric air as can penetrate into the tank, will also be a place of danger.

On board the s.s. Tancarville, the forward water ballast tank had at one time been filled with oil, and at the time she went into dry dock a small quantity of oil remained in this tank, which, being gradually converted into vapour, rose through the hatchway into the space above. It was in this water ballast tank that the explosion occurred. And it was in the space just above this tank that it was supposed a spark passed between the end of a cable and some part of the ironwork of the ship.

The vapour given off by petroleum appears to pass through three distinct stages, according as it is more or less diluted with atmospheric air. When undiluted, it is stated not to be capable of ignition, and to be neither inflammable nor explosive. When diluted with 350 times its bulk of atmospheric air, it becomes explosive, something after the manner of coal gas. When diluted with 1150 times its bulk of air it becomes inflammable,

and after further dilution the mixture becomes harmless; it will neither ignite nor explode.

In the presence of a plentiful supply of air, its diffusion and consequent dilution is stated to proceed very rapidly; and it was on this ground that Dr. Dupré and Professor Redwood held that the gas which emanated from the forward water ballast tank in the s.s. Tancarville, on the morning of the explosion, was so far diluted on reaching the point where it was thought that a spark passed, as to be incapable of ignition.

It will be understood that the question of providing suitable lights for these vessels is not an easy one to determine, as it would be quite possible for the light used in a particular part of the ship to ignite gas in the inflammable state, and that this gas might conduct the flame to another body of gas in the explosive condition, much as it has been proved that coal dust does in coal mines.

Electric lights have now been used for some years on board these ships, as their convenience and apparent freedom from danger early recommended them. The points to be discussed in this chapter, as the writer understands them, are :—

1. What are the conditions under which any part of the electric light apparatus may cause an explosion?

2. How and when do these conditions arise?

3. Is it possible to provide adequate protection against these possibilities, and how?

In reply to query 1, the conditions are—

a. That a spark shall pass between two conductors, and that the spark shall carry a certain energy.

b. That a conductor shall be raised to a yellow heat.

c. That either an inflammable or explosive moisture shall be present in such a position that the spark or the heated conductor shall be in the gas.

In reply to query 2, the condition *a* may arise in several ways. A spark may pass at a switch or cut out, which may have sufficient energy to ignite the gaseous mixture. A spark may pass between the terminal screw of a lamp and its connecting wire. And lastly, a spark may pass between the broken ends of wires connected to opposite poles of the dynamo, between one of these wires and the frame of the ship, where the latter is used as a return or has become connected with one pole of the dynamo, between the severed ends of a wire connected to one side of the dynamo, between two bared wires, if there are any connected to opposite poles of the dynamo, or again between one bared wire and the frame of the ship in the cases already mentioned.

Case *b* can only arise from a current of very much greater strength passing through a wire than it is able to carry without heating, under the conditions present. With a compound shunt wound dynamo, this condition would arise at any time should there be a connection between two wires leading from opposite poles of the dynamo, or the dynamo itself be overdriven in consequence of the inefficiency of the governor of the engine.

A case of not unfrequent occurrence is that of the ends of two wires that are intended to make connection between the supply cables and the lamp-holders, being bared and drawn into the small space left for them in the holder in the naked condition. Such an arrangement leads to a short circuit, with its consequent heating, and

also to sparking. The writer has had cases of this kind often brought under his notice.

Either *a* or *b* may arise at any time from imperfectly insulated cable having been employed, the insulation having perished or been stripped off the cable by accident, or from the close proximity of two badly covered joints, aided by a salt water saturated wood casing.

All of these cases have been mentioned, and fully dealt with by the writer in the preceding chapters. He repeats them here, in order to save readers the trouble of turning back, and to further impress it on their minds.

As a partial reply to the third question, nearly all petroleum-carrying steamers that are fitted with electric light have adopted the shunt wound dynamo.

It will be remembered that the characteristic curve of the shunt wound dynamo shows no current, and no EMF when the external resistance = 0, or when a dead short circuit is formed. Of course with a connection of such low resistance as would rule when the ends of two cables even the full length of the ship were in firm contact, or when one was in contact with the frame of the ship at some distance from the dynamo, the EMF, and therefore the current passing, would be small indeed, as an examination of the characteristic will show.

The principal object of this arrangement would appear to be to extinguish the possibility of a spark passing between two wires connected to opposite sides of the machine, that may be accidentally brought into contact, or between one wire and the skin of the ship as already detailed. With low voltages, such as are used at present for ship lighting, it is well-known that the spark which passes between two conductors through which a current is pass-

ing, is on breaking circuit, and that the EMF which provides the ability to spark, arises from self induction in the dynamo, and in any electro-magnetic coils that may be present. If, therefore, the EMF be extinguished, as it would be with a shunt wound dynamo as generator, when a dead short circuit is formed,—or even if the EMF can be reduced to a very small figure, such that the spark, if any does pass, is harmless,—one serious possibility of explosion is neutralised.

Unfortunately, the protection afforded by the shunt wound dynamo is not complete, and even where such a machine is used, of only 65 volts, should a wire break and its bared end strike any part of the frame of the ship, where that is in connection with the electric light service, or any conductor in connection with the opposite terminal of the dynamo, a spark will pass that will ignite any inflammable or explosive mixture that may be present. In the author's experiments to determine this, the conditions present on board the s.s. Tancarville were closely imitated.

A shunt wound dynamo was driven by the gas engine employed to drive the machinery in the author's works, at a speed which enabled it to furnish 65 volts at its terminals. A connection was made between one terminal of the machine and the bed of the gas engine, and two other wires were taken from the two terminals of the dynamo for use in the experiment. With the 65 volts, touching the wire connected to that terminal of the machine which was not in connection with the gas service, against any of the gas burners in the works, immediately ignited the gas when turned on, and this when the touch was as quickly removed as it was possible

for a man to operate. In fact, when a man literally flogged the top or sides of a burner, gas was ignited whenever it was turned on; and after a few floggings a hole was made in the burner. Rubbing the end of the wire down the rough surface of the iron gas service pipe produced a shower of sparks, but when the wire was pressed firmly on the burner, or on any part of the gas service, and rubbed over inequalities in the metal, so as to produce intermittent contacts, only very feeble sparks were produced, that would not ignite the gas, and would not generate sufficient heat to even part one of the small wires of a strand that was used for experimenting; though in the other experiments it was easy to produce a fused button, about the size of a lentil bean, on the ends of the wires.

The reading of this lesson would appear to be that, where the skin of the ship is connected to the lighting service, either by design or by accident, as was fully pointed out in previous chapters, the breakage of any wire connected with the opposite side of the dynamo may, if the end of the wire falls against some part of the ironwork of the ship, generate a spark that will instantly fire any gas present, before the wire itself becomes harmless.

A little consideration will show that this action of the broken wire is in accordance with the laws governing the shunt wound dynamo, provided that all the attendant conditions are noted. The magnetism in the field-magnets of any dynamo, it will be remembered, takes a sensible time to create, the motion of the molecules of the iron of which the action of magnetisation consists, requiring this time to perform the operation. It also takes a sensible

time to extinguish the magnetism in the iron, so far as it ever is extinguished. There is always that "lag" which Prof. Ewing has so ably studied, and which, when applied through a complete cycle of magnetic reversals, he has termed "hysteresis." A shunt wound dynamo loses its EMF, and therefore the current passing from one terminal to the other, when a short circuit is formed between them, because the field-magnet coils are deprived of the current, and therefore there is no magnetism present in the polar space, to generate an EMF in the armature coils, or very little. But when a short circuit is formed between the terminals of the shunt wound dynamo, the magnetism of the machine is not at once extinguished, and, consequently, if the short circuit is broken again immediately, as it is when the wire strikes the iron of the ship and bounces off, the magnetism still present in the field-magnets of the dynamo, plus the self-induction of the shunt coils themselves, will create sufficient EMF to spark across the break with the energy necessary to fire gas, if present. The use of the shunt wound dynamo also involves another danger. It is well known that the speed of the shunt wound dynamo varies with the load, for a given EMF at its terminals, that is to say, as more lamps are brought into use, the speed of the driving engine must be increased if the light given by each individual lamp is to be maintained constant. Unless, therefore, the variation in the number of lights is very small, or a governor with a very wide margin for regulating the speed can be provided, so that the speed may be altered at will, and yet maintained constant with any given load, the use of the governor must be discarded and hand regulation resorted to, either mechanically or

electrically. With hand regulation it will be very possible that the lights will be frequently over run, and it may happen that individual small wires will be overheated. The choice of the dynamo therefore, that will provide the minimum risk, will depend upon the conditions in each case. Probably the shunt wound dynamo will furnish the smallest risk in the majority of cases, especially if it be made very large for the work it has to do. A further answer to question 3 would appear to be, that in order to minimise the risk of sparking, the skin and body of the ship should be kept out of the circuit altogether.

It will be evident that where the whole body of the ship, not only its skin, but its beams, decks, stanchions, even eye-bolts, and so on, form one side of the circuit, the danger of sparking is ever present.

Where double wiring is used also, frequent tests should be made to see that connection has not been effected with any part of the ship, and when such a connection is formed, the branch circuit in which the connection lies should be switched off completely till the connection is found and removed. The necessary tests may be made with perfect safety with the apparatus described in the last chapter.

A voltmeter used in place of the detector galvanometer, will show more accurately how the matter stands in cases of partial connection between a cable and the ship, such as would arise from the insulation having broken down, the voltage between the ship and one terminal of the dynamo indicating very accurately the extent of the trouble. On board the s.s. Tancarville, though she was wired on the double system, it was quite evident that the

ship was in connection with one side of the dynamo, and it was stated by the chief-engineer that such connections were often made by the small branch wires leading to individual lamps being twisted round the iron support of the lamp, which of course formed part of the circuit, and their insulating covering being abraded. It will be seen that, when such a connection does occur, it would not be sufficient to cut off that branch by severing one cable at a switch. It might be the other cable which was in connection with the ship; and even when the connection was on the cable in which the switch was placed, if there happened to be many lamps on that branch, the connection to the ship would still exist, but with a higher resistance.

It would be wise, therefore, in all petroleum ships to have either double pole switches, or two switches on each branch, one in each cable, at such points that branches in which connections to the ship or to each other may occur, can be quickly cut off from the rest of the lighting service. For the same reason, fuses should be used in both cables. The writer prefers a single switch and a single cut out in each cable, preferably to double pole switches and cut outs for the reasons already given on page 180. The matter is not of so much importance with the low tensions employed on board ship as with higher tensions, but, on the other hand, the apparatus is often subject to both electrical and mechanical strains which they do not get elsewhere. Switches and cut outs should of course be placed where no gas is found.

A further answer to the question (3) would be found in the avoidance of the use of portable lamps which derive their currents from the electric light service by

means of flexible cables. Flexible cables under such conditions are always liable to be damaged by the sharp combings of the hatchways, and hence to lead to sparking. If they are used, the flexible cables should be protected as ropes are protected on board ship, viz. by layers of canvas and well-tarred jute. It would be far better, however, for those places where portable lamps are necessary, to use hand lamps, furnished with either primary or secondary batteries of only a few volts EMF, the lamps themselves being protected by stout glasses.

It would also, in the author's opinion, wherever gas may be looked for, be wise to avoid all loose joints, such as must necessarily rule where the lamp either hooks on to its holder or slips into a socket, and further to avoid, as far as possible, connections between small wires and small screws in such a manner that they may work loose. There is always the danger of the connection being broken, a spark passing, and the heat generated in the confined space, even by a spark of small energy, rendering the metal parts hot, and so firing the gas, or setting alight to some inflammable material that would conduct flame to the gas. It will be remembered that fires have occurred on shore from this cause. The author would prefer that lamps should be made specially for these ships with long terminal wires, the wires being well insulated and firmly welded to the platinum terminal wires of the lamp. These insulated terminal wires could be brought to terminal plates of slate, porcelain, or very hard wood soaked in paraffin, where the cable attachments could be also made in such a manner as not easily to work loose, and in such a position as to be readily visible, and out of gas.

The only other precaution that occurs to the writer is in the construction and protection of the cables.

In the inquiry before mentioned, Dr. Dupré went so far as to express the opinion that the electric light ought not to be used in petroleum ships on account of the possible danger of cables or branch wires being broken, and thereby giving rise to sparks. In the author's opinion this is not the only danger to be feared in connection with cables. The insulating envelope is very liable to perish, and to crack under the strain of the various temperatures to which they are subject, and also from the very heavy mechanical strains produced by the rolling and pitching of the ship in a heavy seaway. Added to this, there is the constant vibration from the main engines, more especially in heavy weather, and the frequent floodings that the cables must receive from the seas which break over the ship from time to time.

Against all these, neither indiarubber nor gutta-percha, nor, so far as the writer is aware, any other form of insulation, is effective if unprotected. Wood casing, though a very good protector against mechanical injury, is itself a source of trouble as soon as it becomes saturated with damp sea water. The water-logged boarding will help to cause the failure of the insulation, and will also convey a small current from one cable to another, particularly at the joints, that will add to the trouble.

Treating the wood something after the way canvas is treated in the manufacture of tarpaulin will partially prevent this; but even then sea water may lodge in the grooves and tend to give trouble. It has been proposed to use lead-covered cables, and to protect the cables also by an armour of iron wires outside the insulation. In

fact, the writer understands that some ships have been fitted in this manner. He would most strongly condemn both lead covering and external armour, and for the following reasons:—First, you can never be sure that, in putting on your lead sheath, or your armour, you have not damaged your insulation. The cable may test all right, work all right for a time, and yet have received a strain at some particular point. The weakness induced by the strain will go on increasing till, on some extra strain being applied, say by the belt of the dynamo coming off, a spark passes between the copper core of the cable and its outer sheath, giving rise to very considerable trouble. Secondly, the presence of an unyielding body, such as the lead casing or the armour, on the outside of cables that are in the position occupied in a ship, where all the supports are in constant motion and may be subject to very violent strains, will tend of itself to increase the strain upon the insulating envelope.[1]

Almost any form of insulating covering to the cable proper may be used, provided a good covering of jute be provided outside all. It has long been the writer's practice to have cables protected in this way for mine shafts. He uses a heavy coating of indiarubber vulcanised, outside of which are laid two thick servings of jute, put on the reverse way to each other, and outside of that again two wrappings of tape soaked in some water-resisting compound. Cables made up in this way give a high degree of insulation, are very flexible, and will keep the wet out for a good many years, and are well

[1] The author has recently met with a case where, he believes, a fire was caused by a spark passing between the copper and iron of an armoured cable; the latter having had a knock in stowing cargo.

adapted for ship work. It will be remembered that jute is itself a good insulator, more especially when, as would be the case in a petroleum ship, it has absorbed a quantity of the petroleum vapour, which also forms the very best insulator known. The petroleum, of course, also helps to keep the wet out. The author agrees with Dr. Dupré that, where a cable consists of a strand of wires, each wire should have its own fuse, where these are employed; but he would prefer that the cable should be made very much larger than would be necessary, so as to provide for this contingency. As already indicated in previous chapters, the author does not view the use of fuses at all with favour in ship work, owing to their liability to be parted by purely mechanical strains. The use of the shunt wound dynamo, therefore, made very large for its work, so as to be practically self-regulating; branch wires and cables made larger than the normal conditions would dictate, and protected in the manner described; the skin of the ship not to be allowed to form part of any circuit in which the dynamo is included; switches and fuses to be fixed in each cable and branch as described, and to be placed always in those places where the petroleum vapour will only reach them in the non-inflammable state; no loose joints; no naked conductors, nor any stripping of the cables; no portable lamps that derive their current from a flexible cable leading to the dynamo;—these appear to be the precautions necessary for the safe use of the electric light on board ships carrying petroleum. With these precautions, and with a careful man in charge, who understands his apparatus and appreciates its dangers, the electric light should be a source of safety.

CHAPTER IX.

CARGO AND SEARCH LIGHTS.

THIS book would hardly be complete without a description of two forms of electric light apparatus that are gradually coming into use, viz. that used for loading and unloading cargo at night and that used for detecting the presence of objects at sea during the hours of darkness.

The utility of the first-named apparatus hardly requires any proof. Given a ship whose loading or unloading has to be done within a certain number of hours, during a portion of which artificial light must be used. If the ship or the loading wharf are either of them possessed of some powerful illuminant, the work can be carried on more quickly, more easily, and with fewer accidents, than where one has to depend upon a number of smoky dock lamps placed below the object to be illuminated. For this work large incandescent electric lamps of from 300 candle-power upwards are by far the best.

They furnish a steady white light, not dazzling like the arc, not smoky or flickering like the oil spray lamps, and they do not go out as long as the dynamo, engine, and cables are in order. No special plant is required for these lamps. They can be run from the dynamo

which is furnishing the other lights in the ship. Nor is it necessary, in most cases, to have a larger plant than would otherwise be required in order to be able to use these lamps. As they are only required in dock when many of the other lamps are not wanted, the latter can be switched off while the cargo lamps are in use.

The lamps themselves should be held by a strong brass lamp-holder made to grip the neck of the lamp, the holder itself being secured above to a strong enamelled iron reflector.

The reflector may be attached to any convenient hoisting gear, and run up to a suitable height by means of a block on the gaff. The leads from the dynamo to the lamp should consist of two parts, one fixed and one movable.

The permanent cables should lead from the switch board, or the immediate neighbourhood of the dynamo, to any convenient point near the hatchway above which the light is required. Near the dynamo a switch should be fitted in each cable, so that when not in use the cables may be completely disconnected from the generator. A cut out may also be fixed in each cable at the same point.

Near the hatchway a pair of connecting pieces should be fixed, mounted either on slate or hard dry wood, preferably the former in this case. The arrangement should provide for the ends of the cables leading from the dynamo being permanently connected to, say, a pair of stout brass blocks in such a manner that they will not work loose with the vibration of the ship; and it should also provide for the cables leading from this

point to the lamp being easily and surely connected to the same blocks, and as easily disconnected.

Permanent connections and connecting pieces may be arranged in this way near each hatchway, so that one lamp can be moved from hatch to hatch. One pair of switches and cut outs may control the whole of these connections, or each set may have its own, as may be preferred.

A switch may also be provided alongside the connecting pieces, or may form one of them, if it is likely that the lamp will be required for two nights running. The connecting pieces and switch, where one is used, should be placed under cover if possible. When in dock it does not cause much inconvenience to bring a couple of leads through a bulkhead door, while considerable protection is afforded by not having the naked brasses, and the slate or wood bases, exposed directly to every sea that washes over the ship.

The cable leading from the connecting piece to the lamp may be one of the numerous forms of twin cable, two cables made into one, or it may consist of two separate cables. The author prefers to have separate cables, each consisting of a large number of wires, like the flexible cord already described for small lamps but larger, so as to be very flexible and easily coiled like a rope, with a medium covering of indiarubber, and then well overlaid with spun yarn.

A good covering of spun yarn laid on either as described, or served on after parcelling, would even be sufficient without indiarubber. But it is wiser to have a covering of the latter as well. It gives the one more pull for coming up.

The current taken by the large incandescent lamps is usually less in proportion than is taken by the smaller lamps. Thus, a 16 candle-power lamp for 60 volts takes a current of 1 ampère to furnish its proper light when new, but a 300 candle-power lamp for the same voltage does not take 19 ampères; it generally takes only 12½ ampères. So that it is more economical to burn these larger lamps, where they can be made available, than the smaller ones.

The reason that the larger lamps take less current is, they are made to work at a higher stage of incandescence than the smaller ones.

In many cases steamers carrying electric lighting apparatus have used a ring of small lamps, 16 candle-power, under a large reflector. As will be seen, from what has gone before, this plan is by no means so good as the use of the large lamps. You do not get as much light from a certain current, nor can you get such a good light at all, as you cannot get sufficient small lamps in position. You have two and sometimes four connections for each small lamp in place of the two only required for the large lamp, and it is much easier to protect the large lamp from breakage than the small one.

The author is not aware if arc lamps have been used for cargo lights. In his opinion they are only adapted for one class of work, that to be presently described, viz. SEARCH LIGHTS. If used for cargo lamps they are certain to give endless trouble, to require cleaning, and very thorough cleaning, every time they are used, to require regulation every time they are used also. And

[1] The large incandescent lamps that have been made of late take the same current proportionally as the smaller ones.

in many cases, by the time the lamp was regulated, the cargo would be out and the fresh cargo stowed.

For SEARCH LIGHTS, however, the arc lamp is at present the only one that can be used. The object of the search light, as already explained, is to enable a captain to have a good look round the horizon after dark. At present their use is almost entirely confined to ships that go through the Suez Canal, and to men-of-war and their allies—shore batteries.

The regulation of the Suez Canal Company, allowing ships that are provided with such lights to pass through the canal at night, has been the means of introducing a number of them into the merchant marine; while the necessities of modern warfare, and the development of torpedoes, have obliged men-of-war to use them in both actual and mimic warfare, to enable the officer of the watch to detect the presence of a torpedo boat running out under the land.

But there are many other cases where the search light would be of very great service.

In approaching the coast on a very dark night, foı instance, every officer who has entered a particular port two or three times becomes familiar with the appearance of the land near. What assistance it would be, on a badly lighted coast, to get a glimpse of that portion you are near to!

In very thick weather, and in fogs, the search light would be of some use. Electric lights do not penetrate fogs very readily, but their rays do go some way beyond the ship, and that small distance might mean safety, in certain cases where otherwise disaster would result.

In thick weather in the channel, too, however short a distance the rays for the search light extended, one of

those rays might reveal an unsuspected lee shore in time to get off. The arrangement of the search light is as follows:—

The light itself proceeds from the spark which passes between two points in a circuit, purposely broken there for the purpose. The electric spark, which passes between any two points, always takes its colour from the substance forming the point from which it passes. In passing across the break, whether made for it as in the arc lamp or accidentally formed as in the cases that have been described, the spark always carries away with it a small portion of the material of the positive pole, the point *from* which the current passes, assuming that the current passes from what we know as positive to what we know as negative. This small quantity of material carried away by the spark is converted, by the intense heat present, into vapour; and as each substance assumes its own characteristic colour in burning, the spark also assumes the colour of the positive point, whatever that may be.

As pure carbon emits a white light in burning, that is the colour of the spark passing between carbon points, and for this reason carbon is employed for generating light in the arc lamp.

Besides the original spark, which passes between the separated carbon points, the continual passage of a series of sparks soon creates a bridge of carbon vapour at a very high temperature, whose electrical resistance is very much less than that of the air space whose place it occupies.[1] This bridge has been termed the arc, the writer believes, because in the early days of experiments with sparks between carbon points, when very long arcs

[1] The greater portion of the light rays are emitted from the point or crater of the positive carbon.

or bridges were often made, it was a common experiment to cause the bridge of flame to move out of its direct path, from carbon to carbon, by the aid of a strong magnetic pole presented near it.

Something similar will have been witnessed by many readers at the Crystal Palace Exhibition, where an arc is formed having an EMF of 20,000 volts.

The arc lamp, then, is simply an arrangement for holding a pair of carbon pencils in such a position that they may be able to maintain an arc between one pair of their extremities as long as the light is required. It will readily be understood that, as the spark tears away a small portion of carbon every fraction of a second from the positive pole, and wastes a smaller portion of the substance of the negative pole, the distance between the carbon points would gradually get longer, and unless either the resistance offered by the vapours in the arc decreased, or the EMF present between the carbon points decreased, the lamp must go out, because the spark would cease to pass.

For this reason various forms of mechanism have been designed for the purpose of maintaining the carbon points at about their normal distance apart. It will not be necessary in this book to describe the various methods employed. They are none of them suitable for search lights, and for the following reasons:—

Except where an alternate current machine is used, the two carbon points consume at different rates, the positive carbon burning at about twice the rate of the negative. Further, any inequality in the material, in the current strength, or in the length of the arc, the space between the carbons, will lead to further inequalities of burning, to irregularities of shape, and to considerable

variation of the direction in which the light emitted escapes into the surrounding atmosphere.

A description of a search light apparatus will show at once that this state of things will not do.

In a search light apparatus the endeavour is made to collect all the rays emitted by the arc, and to form them into one intensely brilliant beam, which shall be able to illuminate objects at a great distance from the ship.

It will be remembered that any source of light, whether it be a purser's dip or the sun itself, sends out luminous rays in every direction—that, in fact, it illuminates, feebly or brilliantly, the internal surface of a sphere, whose radius is the distance from the source of light.

It is obvious that a very large portion of those rays are of no use for lighting, especially on the deck of a ship. Those, for instance, which go more or less directly down, those which go directly up, and those which go in the direction we do not require them.

It is obvious, also, that if by any means we can bend these useless rays out of their natural course into one particular beam, we shall intensify the light in that direction in proportion.

In the search light apparatus this is accomplished by the aid of reflection and refraction.

Behind the arc is placed a parabolic mirror, whose office is to reflect the rays going behind and direct them to the front. In front of the arc is placed a series of lenses known as a dioptric apparatus, whose office is to bend the upward rays down, the downward rays up, and to allow the reflected rays from behind to pass through as far as possible without charge. The combined result

is the dazzling fan-like flame, so familiar to us all, which illuminates objects within its arc at a distance several times beyond that which would have been possible with the arc alone.

In order, however, that reflection and refraction may take place to the best advantage, it is necessary that the source of light should be in the focus of the mirror and in that of the lenses, and should remain there.

It will be seen at once that any arc lamp which maintains its arc, as most of them do, by allowing the upper carbon to gradually work down, as both burn away, would soon place the source of light out of the focus altogether, so that the lenses and reflector would only conceal the light instead of intensifying it.

In a few arc lamps the plan has been adopted of bringing the lower carbon up as the upper one falls, so as to maintain the position of the arc approximately constant; but no arrangement of this kind is likely to be successful for long, as no carbons burn so exactly in proportion as would be required.

The plan adopted, therefore, is to regulate the burning of the lamp used in search lights by hand.

An electro-magnet attached to the apparatus sometimes separates the carbons in the first instance, performing the operation known as striking the arc, and after that the attendant, by means of screws, keeps the arc always in the focus. In some forms of search lights the whole thing is done by hand.

The whole apparatus is usually mounted on a platform which can be fixed in any convenient position, and it can be worked by a current from the dynamo just as cargo lights are. In fact, the same connecting pieces could be used.

For providing the current, either a margin can be left in the output of the dynamo above the normal requirements, always a wise measure, or a portion of the other lights can be turned off while the search light is in use.

As the search light is only required occasionally, and for a short time, this would not cause much inconvenience, nor does the matter of the attendance. The apparatus should always be kept clean and ready for use, just as side and masthead lamps are.

In going through the Suez Canal a plan frequently adopted is to have the lamp on a small platform under the bows, the attendant being there to regulate the lamp as the ship goes through the canal, and the beam being kept well out of the eyes of those on deck.

In lighthouses, where the same kind of lamp is used, regulation is effected by clockwork with special modifications. An attendant is always near, however, and there is a second lamp always ready on a sort of turn-table, that can be connected and got in focus instantly should anything happen to the one in use.

Lighthouses also generally employ alternate current machines, which lessens the necessity for regulation, the consumption of the two carbons being about the same, theoretically exactly the same.

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